INNOVATION IN ELECTRON MICROSCOPES AND ACCESSORIES

by

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ABSTRACT

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An innovation, narrowly defined, is the introduction by a firm of a product or process new to the economy. To examine the innovation process, this study focused on a single device--the electron microscope--and the history of innovation in its development from the 1930's to the present. The electron microscope is a device which by use of electrons can magnify the image of objects over one million diameters.

Data on seventy-nine innovations in the electron microscope and accessories was collected and analyzed to test a number of hypothesis developed from a preliminary analysis of the data.

Data was collected from books, periodicals, conference proceedings and interviews.

These were the principal results:

A new concept is introduced that states that some people that produce innovations are interested only in the instrument and not the end use of the instrument. These people, named 'instrumentalists,' work in non-profit organizations and have relationships with electron microscope manufacturers who manufacture the innovations of the instrumentalists. Innovations by instrumentalists occured mostly in the early history of the electron microscope.

Manufacturers of electron microscopes perform innovations and are the only source of cost reducing innovations.

The innovations of users of electron microscopes who are primarily interested in applications not the microscope for its own sake, are primarily biologists. Their innovations deal mostly with specimen preparation devices and are manufactured by manufacturers who make parts of or accessories for electron microscopes but not total electron microscopes. The number of innovations performed by users has increased with the number of electron microscopes in use.

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CHAPTER I: INTRODUCTION

Why Study the Process of Innovation?

The practical reason for stydying the process of innovation is that through study comes understanding and with understanding, the variables identified as underlying successful innovations can hopefully[1] be manipulated to increase the rate of successful innovations. In short we study innovation so that we can be better at it.

The desire for technological innovation and the creation and use of new technological things seem to be deeply rooted in the Western outlook on life, an outlook which is future oriented, rather than past oriented as are some Oriental cultures. Western society, and in particular the United States, generally believe that "new is better" and that "we must have progress". Recently, environmentalists and others have questioned both the need for technological change and the desirability of the concomitant social changes. While these challenges have had noticeable effect in very limited economic areas (e.g. the location of new power plants), they have had no noticeable effect on the Western economies as a whole which are philosophically and practically committed to innovation as being worthwhile.

The improvement of the innovative process can be impor-

[1] All statements about the future control of the process of innovation should be qualified since the possibility exists that innovation is not controllable.

tant on microcosmic and macrocosmic levels: Individual firms, if they can be more innovative, can be more successful in the market place, grow as organizations, and return higher earnings to investors. On a national level, nations that can be more innovative than they have been in the past may be able to increase their standard of living and their competitive position in world markets. National governments that have gained understanding of innovation could possibly promulgate policies that would facilitate increased innovation. On a world-wide scale, increased innovation may help bring forth more technical changes (e.g. high yield crops, birth control) that would attenuate disease and hunger throughout the world.

Innovation, A Definition

The definition of innovation[2] that we will use in this study is similar to Myers and Marquis' definition:

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[2] In this study, we limit ourselves to technical innovations as opposed to social innovations. To illustrate this distinction, birth control pills are considered a technical innovation but the use of birth control is a social innovation.
The interdependence of social and technical innovations is illustrated in the above example: birth control pills have contributed to the use of bith control while the acceptance of birth control made the development of the pill more reasonable (for who would invest a lot of research in a product that was not socially acceptable).

"The term 'innovation' will here be defined broadly as the introduction by a firm of a technical change in a product or process. Following Myers and Marquis we also add the restriction that the change be new to the market.[3]

In gathering the data for this study we focused on the first company to commercialize an innovative product or product improvement but there are some cases where the second and third commercializers were initially considered. During analysis of the data, however, it became apparent that second and later commercilaizers bring out their product under different circumstances than first commercializers. For example, RCA introduced their standard double condenser lens in response to user demand. This demand was partially, if not substantially, motivated by the user's seeing the double condenser in use on existing Siemens and Philips microscopes. This induced need, as it were, biases the sample, so it was decided to eliminate from the data base any innovations that were not first commercializations.

To devise an operational definition of innovation which will allow us to judge clearly which innovations fall within our definition, we add the following constraints:

1. Limited or short run commercial products are considered innovations. Products that were developed but not offered to the market are

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[3]For discussion of electron microscope technical features see references Haine [31] and Thomas [78].

not considered innovations.

2. Two or more products that are functionally the same but realized by different technical means are regarded as separate.

3. Were a large number of small improvements over time on the same device resulted in as significant change, where regarded in the aggregate, the group is considered as one innovation for the purpose of the study (There are four such cases in the data).

4. In the case where a system has been built for an explicit or obvious objective[4] (e.g. less expensive), only the one new feature that contributed the most to the design objective is listed as an innovation. Given the issues of the present study this constraint avoids multiple counting of innovations that would bias the data with a large number of non-independent data points.

5. Since the survey deals with the electron microscope and related products we operationally restrict our definition of innovation to those which deal with the transmission elec-

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[4]Three such cases were encountered. Each was described by a paper by the microscope designers explaining how and why the low cost design was carried out. The data on all these innovations was later used to examine the nature of cost reduction innovations.

tron microscope system itself (including power supplies and vacuum pumps attached to the microscope) and with products used for the preparation of samples for viewing in the transmission electron microscope.

The Present Study

The introduction suggests that great value and some noble purpose exists in the study of innovation. Now we consider the mundane work of studying innovation. The work presented here has been delimited in such a way so as to be both manageable for a thesis topic and meaningful as a small contribution to the study of innovation. We studied here one data point, as it were (the electron microscope and accessories), which, when combined with other data points from other studies, can be used to formulate and test general hypotheses about the process of innovation.

The Hypotheses

Data was initially collected[5] and reviewed. A preliminary analysis of the data suggested numerous questions about innovations in electron microscopes and accessories. These questions gave rise to several hypothesis which we desired to test in this study:[6]

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[5] The data was initially collected as part of an ongoing study of innovation conducted by Professor Eric von Hippel, at the Sloan School of Management, MIT.

[6] These initial hypothesis were not formulated using the precisely defined terms that were used in the final data analysis.

1. Certain individuals are involved in innovations because they are interested in making a better electron microscope.
2. Most innovations are initially developed outside the commercializing firm.
3. The users of electron microscopes are a significant source of innovation in this area.

The initial analysis of the data along the issues mentioned above suggested further questions:

1. Why were the innovations of electron microscope users distributed over time in a particular way?
2. What was the relationship between the developers of innovations and commercializers?
3. Was there a relationship between the function of an innovation and whether or not the developer of the innovation was a user or a commercializer.
4. Was there a difference between innovations commercialized by manufacturers of complete electron microscopes and manufacturers of parts of electron microscopes.

<u>Why the Electron Microscope was Chosen for Study</u>

The electron microscope was selected as the focus of our study of the innovative process because it is considered to be scientifically complete, its evolution is well documented and it is a mature commercial product. The scanning electron microscope is not, as yet, a mature product.

The electron microscope as a whole is considered to be a very important innovation in terms of scientific and technological developments. It was cited for example by Jewkes[7] on his list of important innovations. Project SAPPHO[8] studied the scanning electron microscope, which is a close cousin to the electron microscope, and so some slight comparability is provided between this study and the SAPPHO study. Secondly, the historical documentation on the development of the electron microscope is quite good. Because manufacturers wanted to quickly publicize the advantages of their microscopes to the scientific community, they had articles or quasi-scientific articles written about them. At the same time, innovators in the field of electron microscopy were usually in the university or institute environments and they desired to publish their findings as soon as possible. These papers provided dates and good technical descriptions of what was occurring. Cross references are provided by authors that cite previous workers' publications. Finally the electron microscope is a mature product, commonly accepted, with thousands of units in use.[9]

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[7]See Jewkes, Sawyer and Stillerman [45]

[8]See Project SAPPHO [16]

[9]An additional advantage to choosing the electron microscope for study is that the author had some experience and technical knowledge of the instrument before starting the project See proceedings [80] p. 617 and 169.

Some of the disadvantages of choosing the electron microscope, given the length of this study, is that its development was interrupted in Eruope by the war, the first microscopes having been produced by Siemens in 1939 and 1940. Furthermore, most of the major microscope manufacturers are located outside of the United States, in either Europe or Japan. This made some of the information gathering rather difficult. In the U.S., RCA was the only manufacturer of electron microscopes and they subsequently sold (1969) their business to another manufacturer, who has since become defunct.

The related instruments all deal with specimen preparation or accessories for the electron microscope. These related instruments are essential to the electron microscope since without these devices the electron microscope is operationally useless.

<u>The Electron Microscope</u>

In recent years the electron microscope has become a commonly used research instrument, particularly in the fields of biology and materials science. An estimated 18,000 instruments are now in use, about half in the United States.

An electron microscope is an optical instrument, similar to an optical microscope, in which a beam of electrons, rather than light, is used. The electron beam is focused by means of electromagnetic or electrostatic lenses to form an enlarged image of an object on a fluorescent screen or on photographic plates. Electronic equipment or batteries provide high voltage (30,000 volts or more) for the electron beam and lower voltages for the magnetic lenses. A series of pumps removes air from the inside of the microscope so that the electron beam travels unimpeded by gas molecules.

A typical electron microscope is over six feet tall and, with its power supplies, weighs between one and two thousand pounds. Depending on its capabilities, electron microscopes sell for between $10,000 and $100,000.

The term 'electron microscope' commonly means 'transmission electron microscope', that is, a microscope where the electrons pass through the object being studied. In recent years a number of different types of electron microscopes have been developed: scanning electron microscopes, reflection electron microscopes, scanning transmission electron microscopes and high voltage electron microscopes (electron beam voltage greater than 500,000 volts.) This study is confined to the transmission electron microscope which following common usage will be called the 'electron microscope'.

Products related to the electron microscope are those products used in preparing specimens for viewing in the microscope (e.g. ultramicrotomes for cutting thin sections of samples) and devices for manipulating the sample while it is on view in the microscope (e.g. heating stages that heat the specimen).

CHAPTER II: DATA COLLECTION

Introduction

The data base of this study was collected from books, articles, conference proceedings and interviews, see bibliography and Appendix IV. This chapter describes the methods of data collection. The detailed definition of an innovation is given in Chapter I page 10 and other definitions are given in Chapter III page 23.

Sample Selection

The first step was to develop a list of innovations in electron microscopy. This was done by literature review and interviews with experts in the field. From general reading of the literature (expecially references 24, 59, 85) the list of innovations was expanded and tentative answers to a number of our initial questions were obtained. Three lengthy interviews with Dr. John Coleman, formerly of RCA and now at MIT, provided a list of innovations that he judged to be significant as well as a considerable amount of background information on the development of the electron microscope.

The identification of electron microscope innovations commercialized by non-electron microscope manufacturers[10] was accomplished by interviewing the principals of these companies. These interviews both identified innovations and

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[10]The term non-electron microscope manufacturer is used to indicate a manufacturer that produces and sells to the end use electron microscope parts and/or accessories but does not make complete microscopes.

provided answers to a number of the questions. Also, these interviews suggested additional sources of information (often the user who had developed the innovation) which were later used to make the information on the innovations more complete.

These efforts produced a list of 113 electron microscope and related product innovations on which further information was gathered. Thirty four innovations were eliminated because they did not meet our definition of an innovation or because data on them was insufficient or redundant. The final sample size was seventy nine.

Data Collection Methodology

The people interviewed were selected because they were either users (in the usual sense), instrumentalists (see page 24 for a precise definition) or they worked for commercializing firms. An additional means of selection was to talk with people who were thought to have knowledge about a specific innovation. In all 23 persons were interviewed (see Appendix III for names.)

Except for Dr. Coleman of MIT, all interviews were conducted by telephone, a necessity considering the geographic separation of the informants.

Prior to each interview some time was spent finding out from the literature what the individual's constibutions were and becoming familiar with them. Each interview was approached on an individual basis.

In most cases the person interviewed had been associated with the development of one or more innovations and so the first question dealt with the interviewer's particular innovation. The first questions were open-ended, e.g. "I understand that you developed _____, could you tell me how this came about?" or, "What were the circumstances under which ______ became a product?" Later in the conversation questions were made more specific: e.g., "Did you contact him or did he contact you?" "Did users indicate their needs by writing to you or talking to you?"

Most people interviewed were very cooperative. Among those who had been involved in the "early days" of electron microscopy (1939 to about 1960) there exists a sort of fratermity, with everyone knowing everyone else, although they are often out of touch with each other now. The opportunity to talk about the nostalgic "good old days" (which some people specifically mentioned) provided a free flow of rich information.

The following questions formed the basis of both the interviews and the literature investigation in developing information on each individual innovation. These questions were formulated to investigate the issues raised on page 13.

1. Identification of an innovation: what was the particular innovation and why was it considered an innovation? The objective here was, in addition to gathering specific facts, to understand how the innovation fit into the evolution of the microscope.

2. What was the name of the first commercializing firm? What other commercializers were there?
3. Why did the firm decide to commercialize the innovation? Was there a demand from potential users? Did a potential user develop the innovation? If the commercilaizing firm identified a need for a particular electron microscope innovation, how did they identify the need?
4. Historic background: (This information was both specific and general.) What was the environment surrounding the innovative process? How many potential users were there thought to be? If the user developed the innovation, how many units were built before commercialization? Why were they built? How did the potential user communicate with the initial commercializing firm? Did the firm contact the user who developed the innovation? What was being used before the innovation occured? What was the perceived need for the innovation?

The above list illustrates the kinds of questions asked. Answers were not always avialable. In some cases information was ambiguous or conflicting, so that a judgement had to be made as to whether or not to use the data from a particular information source or in some cases whether or not to include the specific innovation in the sample.

The raw data collected on each innovation was summarized in the form of short answers to the principal questions while the total information from the interviews was kept intact for use in understanding the environment and for use as a source to help answer other questions that might occur. Often the information from one interview was helpful in providing collateral information, new sources of information and gaining specific information on and insights into other innovations.

CHAPTER III: ANALYSIS OF THE DATA

Introduction

In this chapter trends in the data are examined and hypotheses are formulated and statistically tested against the data.

The first part of the chapter sets down the definitions that were used in classifying the data. These definitions are important in understanding the tables in the chapter and are necessary if any attempt should be made to replicate this study on electron microscopes or other instruments or industries.

In formulating these definitions two problems were encountered. First, the words we sometimes like to use already have established meanings that are not the exact meanings we need. Second, the commonly used term'innovator' did not fit our classification of elements of the innovation process. According to our definition of innovation, an innovator would have to be a person that performs the two acts needed for an innovation to occur: making a physical embodiment of the innovation and the commercializing the physical embodiment. Such rarely occurs and hence two separate terms are used in this study.

Definitions

Performance of an Innovation: An innovation by our definition, (see page 10) must be a device or process that is commercialized. We wanted, however, to consider where and when the first technical realization of the innovation (before commercialization) took place and who was responsible for it. The 'Performance of an innovation' will be used to refer to the physical bringing into being of a device or process that is later commercialized. The terms "inventor" and "invention" are not used here because many inventions are never commercialized and hence are not innovations in the sense in which we are using the term.

User: A person who performs an innovation. For example, the gyrocompass was improved by innovations by Anschistz-Kaempte because he wanted the compass for navigating while exploring the North Pole.[11] Sometimes users are easy to identify from their published papers because they describe their device and tell how and why they are going to make use of it and why the designs were undertaken.

Instrumentalist: This term only applies to persons producing innovations in the field of instruments who are concerned with the instrument itself, in our present case the electron microscope and instruments used in specimen preparation. This person wants to build a better instrument. In the case of electron microscopes, these people may be motivated by the desire to see what was never seen before, and perhaps, ultimately to see the atom. They might also be motivated to use

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[11] See Jewkes et al. [45] , p. 254.

the electron microscope as a vehicle to learn about electron optics.

We identified instrumentalists on the basis of certain characteristics of the papers they published: these papers usually all deal with the same instrument, or in some cases applications and typically they deal with technical aspects of the instruments. The classification criterion for "instrumentalists" used in this study, was that the person had at least three[12] more technical publications on the functioning or design of the electron microscope than on any other technical subject. Although the operational definition does not specifically exclude instrumentalists that deal with specimen preparation devices, no such persons were found in the data we collected.

Cost Reducing Innovation: An innovation developed with the specific intent of cost reduction and cited in the literature written by the commercializing firm.

'Non Profit' and 'Commercial Institution: 'Commercial' means any institution whose purpose is to make a profit. All others are considered non profit in this study.

'Primary Area of User Interest' was determined by the topic

[12]The number three was picked because it gave a concrete measure that produced a group of instrumentalists that agreed with our a priori definitions: four papers made the group artificially small while two papers included non-instrumentalists in the group.

and numbers of paper published by the individual in question. Since the objective was to separate biologists from non-biologists[13] e.g. material scientists, the criterion was that a biologist had one more paper in biology than he had in any other field. American Men of Science[14] was used when necessary as an authority to identify the person's field directly.

'An electron microscope manufacturer' is a firm that manufactures complete transmission electron microscopes as opposed to simply portions thereof.

'Inventor': While the instrumentalist is primarily concerned with the instrument, the inventor is primarily concerned with the process invention or innovation (in a broad sense). Bakelite and the Molten bicycle are products of inventors, people who spent their time working on problems for the purpose of producing innovations. An inventor, by our definition, has several innovations in different areas.

Note that an instrumentalist is not an inventor that concentrated on one instrument, but in practice the difference may be difficult to see. In our research this becomes a minor problem possibly encountered in the case of employees who are always assigned to one instrument in the commercializing firm. No innovations by inventors were found in the data.

The definition is presented here because Jewkes et al. find that the inventor is an important source of innovations,

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[13] See page 41 .

[14] Reference [27].

so we must be ready to identify any inventors that may be found.

Examining Data for Bias

In a survey based study there is often a possibility that the results have been biased by the way in which the data was collected or that there are biases in the data sources.

Of particular interest in this survey is the possible biasing effect of persons associated with RCA. A possible bias arises because RCA was the only significant United States source of electron microscopes from their first commercial unit in 1941 until 1969. Many of the people interviewed had been associated with RCA microscopes at one time or another.

That data were classified as single source, multiple source, RCA source and non-RCA source. Single source interview data were considered to be the least reliable and single RCA data could reflect a bias due to the source. In some cases however, only a single source had the data we were seeking.

Table 1, below, Percent Multiple Source Data Points in Various Categories, shows that much of the data in use is multiple source and therefore relatively reliable.

		All Data Points		
		Multiple Source	Single Source	Total
Innovation	Commercializer	(23) 68%	(11) 32%	(24) 100%
	Instrumentalist	(20) 86%	(2) 14%	(22) 100%
	"User"	(15) 65%	(8) 25%	(23) 100%

Table 1: Sources of Data

In Table 2 below, we see that RCA data as a sole source existed in a low percentage of cases.

		All Data Points		
		RCA Only Source	RCA Not Only Source	Total
Innovation Performed By	Commercializer	(11) 32%	(23) 68%	(24) 100%
	Instrumentalist	(2) 9%	(20) 91%	(22) 100%
	"User"	(2) 8%	(21) 92%	(23) 100%

Table 2: RCA Data Sources

Due to the large number and diversity of the information sources most data were totally or partially collaborated by more than one source. We assumed that agreement of various information sources on a single point of information increased their reliability on issues where they were the only information source. We conclude, therefore, that our data has not been compromised by an over-heavy dependence on RCA.

Testing the Hypothesis

The next section describes in detail the propositions that were tested with the data base. First the classification of the "instrumentalist" is tested to see if it effects interpretation of the data. Next the relationship between instrumentalist and commercializer is explored. In further tests, the innovations are divided into four categories according to function. These four categories are tested against the three sources of innovation, commercializer, instrumentalist and "user", to gain some insights into the nature of the of the innovations of the individual sources. Innovation effecting cost reductions are then examined. The innovations of "users" are then explored relative to what the "user" affiliation and the type of commercializer. Lastly, data is presented on the distribution, in the life of the electron microscope, of the innovations produced by the different sources. The depth of the data was sufficient to only partially explore why particular distributions of innovations over time have occured.

Statistical Treatment of the Data

Each question that the data is used to try and answer was analyzed and statistical tests of significance wereapplied. The relevant data is presented in tables so that the reader can get a "feeling" for the data. The statistical significance is reported below the table when statistical significance is relevant. It represents the probability that there is no relationship between the variables in the table. Low 2's are of course prefered except when the hypothesis is that there is no relationship between the variables.

The book Nonparametric Statistics[15] has been used both as a guide and a source of statistical tables.In some of the one by three tables the number of data points has been too small to apply the Chi Square test. In these cases α is computed by combining the two smaller categories and making

[15] Reference [75].

a biomial test for α, and calling it α_1. The test is conservative since α_1 is always larger than α.

Importance of the Concept of an Instrumentalist

At the beginning of the data analysis it was considered that innovations were performed either by commercializers or users. It was discovered, however, that by sub-dividing all users into two categories, 'users' and 'instrumentalists', additional insight into who was performing innovations could be gained. We use this sub-division technique first to examine the effect of the developer of the innovation on what type of firm does the commercialization, and then consider the relationship between the instrumentalist and the commercializing firm. Observe the difference between Table 3 and Table 4.

		All E.M. Innovations		
		E.M. Mfg.	Non E.M. Mfg.	Total
Innovation performed by	Commercializers	(29) 85%	(5) 15%	(34) 100%
	"Users" and Instrumentalists combined	(26) 58%	(19) 42%	(45) 100%

Table 3: Electron Microscope and Non-Electron Microscope Manufacturers. Chi Square = 12.8, $\alpha < .001$

		All E.M. Innovations		
		E.M. Mfg.	Non E.M. Mfg.	Total
Innovation performed by	Commercializer	(29) 85%	(5) 15%	(34) 100%
	"User"	(4) 17%	(19) 83%	(23) 100%
	Instrumentalist	(22) 100%	(0) 0%	(22) 100%

Table 4: Chi Square = 43.1 $\alpha < .001$

We find in Table 6 that the innovations of instrumentalists are manufactured only by electronmicroscope manufacturers. This is particularly interesting when we consider that all but one of the instrumentalists are associated with non-profit institutions, see Table 5 below. True, if the "instrumentalist" is employed by the commercializer we do not define him as an instrumentalist. But there are many corporate research laboratories of commercial institutions where the instrumentalist conceiveably could be located: twenty-seven percent of all physicists (physics is a common background of instrumentalists) are employed by profit oriented organizations.[16]

Affiliation of All Instrumentalists Having at Least One Innovation

Non Profit	Commercial	Data Incomplete	Total
(7) 64%	(1) 9%	(3) 27%	(11) 100%

Table 5: $\alpha = .274$

One explanation is that the instrumentalists are ahead of the state of the art (why the E.M. manufacturers' people are not ahead is another question). Another explanation is that they have a close relationship with the E.M. mfg. More than half of the instrumentalists consulted for E.M. mfg. or were hired by them after the instrumentalist had performed his innovation.

16 See Skerington [77], p. 340.

All Instrumentalists Having* at Least One Innovation

Hired or Consulting	Neither	Data Incomplete	Total
(for E.M. mfg.) (7) 70%	(1) 10%	(2) 20%	(10) 100%

Table 6: α = 172

Innovations Attributed to All Instrumentalists* Having at Least One Innovation

Hired or Consulting	Neither	Data Incomplete	Total
(17) 85%	(1) 5%	(2) 10%	(20) 100%

Table 7: α <.001

Another possible explanation for the large number of instrumentalists' innovations commercialized by electron microscope manufacturers is that the electron microscope manufacturer regards the instrumentalists as experts and the "users" not so, hence the manufacturers listen to instrumentalists. The evidence for the commercializers considering the instrumentalists are hired or consultants to the commercializers.

Furthermore, if the electron microscope manufacturer has made an error in estimating the market demand for an innovation, the microscopes will probably sell with the new feature, in spite of it. Even if the microscopes do not sell

*One instrumentalist has been removed from the group because his innovations took place 33 years before there were electron manufacturers to consult.

the firm is large enough to absorb the loss.

We now consider why non-electron microscope manufacturers do not commercialize the innovations performed by instrumentalists. In principle, a non-electron microscope manufacturer could hire an instrumentalist to consult as the electron microscope manufacturers do and produce the innovation he has performed. This has happened for products closely related to electron microscopes. For example the Canalco company (discussed below) had the consultation of W. Nixon, a physicist and expert in x-ray microscopes from Cavendish Laboratory, Cambridge, England (Part of Cambridge University).

Let us consider a manufacturer of electron microscope parts and accessories and their experience in producing products in competition with a manufacturer of complete electron microscopes.

A non-electron microscope manufacturing company, Canalco of Rockville, Maryland produced a number of "innovations" in electron microscope parts which were used on RCA microscopes. These parts were new for RCA microscopes but the innovations had already been in production in European microscopes. In 1954 RCA introduced the EMU 3-A electron microscope which made many of Canalco parts standard features so that Canalco's market, which was limited to supplying equipment for old instruments (about 400 of them) became saturated and disappeared.

The non-electron microscope manufacturers are all small companies and probably cannot risk direct competition with the large microscope manufacturers. There is not sufficient data to support the above hypothesis because Canalco is the only example available of a non-electron microscope manufacturer attempting to compete directly with a microscope manufacturer. In some industries, customers will hesitate to buy equipment from two suppliers for use in the same system. Canalco, however, did not have this problem—a number of thier products sold to three-quarters of the available market.

It is concluded that the innovations produced by instrumentalists are commercialized by electron microscope manufacturers because the electron microscope manufacturers have close relationships with the instrumentalists and the non-electron microscope manufacturers cannot compete directly with electron microscope manufacturers, but, it is not clear whether this is a cause or effect of the instrumentalists' relationships with the electron microscope manufacturers.

Further Analysis of the Data

All microscope innovations were divided into four categories, based on the function of the innovation. These categories will be referred to as 'areas' of innovation. The functional categories are:

1. Electron beam directly affected: Innovations in this category directly affect the electron beam in the electron microscope. The innovations include the gun, lenses, pole pieces, stigmators and apertures.

2. Services brought to the microscope: Innovations in

this category involve the vacuum system, the lens current and high voltage supplies and image recording system. The common feature of these microscope subsystems is that their performance can be simply specified at some minimum value and improvement above this value does not improve the microscope's performance (e.g., 2 lens current supply to "provide 100 milliamperes with no more than .001% variation in thirty seconds time" completely specifies the lens supply). A further common feature of the "services" is that their technology was already partially developed before the birth of the electron microscope.

3. Usability of the electron microscope: Innovations in this category make the microscope easier to use and more adaptable to different uses. Included in this category are innovations dealing with movable (as opposed to fixed) apertures, specimen manipulation devices and air locks.

4. Specimen preparation: Innovations in this category deal with devices used to prepare specimens.

To learn more about the nature of the innovative process we examine the number of innovations performed by instrumentalists, commercializers and users in these different functional areas.

Instrumentalists

From Table 8 below we see that the instrumentalists tend to produce innovations which effect the electron beam. Table 9 shows a comparison between the percentage of instrumentalist innovations related to the electron beam and the percer of combined innovations in three other "areas" of innovatic

		All E.M. Innovations				
		Effects Elec- trons	Usa- bility	"Services"	Spec. Prep.	Tota
Innovation Performed by	Comm.	(13) 38%	(9) 26.5%	(9) 26.5%	(3) 9%	(34) 100%
	"User"	(4) 17%	(1) 4%	(2) 9%	(16) 70%	(23) 100%
	Instru- mentalist	(17) 77%	(4) 18%	(1) 5%	(0) 0%	(22) 100%

Table 8: Statistical significance $\alpha < .001$

E.M. Innovations by Instrumentalists		
All Other	Effects Electrons	Total
(5) 23%	(17) 77%	(22) 100%

Table 9: $\alpha < .005$

What explanations are available for the instrumentalis concentration in innovations affecting the electron beam? Explanation #1. Instrumentalists are primarily interested . the academic discipline of electron optics.

Unfortunately this explanation cannot be tested becaus the electron microscope people and electron optics people (assuming that two separate groups do exist) are not easily separated on an intuitive basis and a qualitative basis see impossible to find. Dr. Coleman has suggested that the elec tron optics people tend to be involved with specialized elec tron microscopes, such as one using the hyperbolic lens.

Clearly Marton is interested primarily in the electron microscope and not electron optics.[17] The primary interest of the others is not easy to determine and may well have shifted with time.

Even if it could be shown that all instrumentalists were primarily interested in electron optics the reason why they do not innovate in other areas as well would still require explanation. To explain the data by saying that instrumentalists are primarily interested in electron optics is inadequate and difficult to demonstrate.

Explanation #2. Instrumentalists were not trained in other areas (e.g. electronics and vacuum systems) and therefore do not make contributions outside of their area of training.

The first part of this explanation is a sort of truism in that many instrumentalists received their training by building electron microscopes. But in building electron microscopes (and producing innovations at the same time) they had to build power supplies and vacuum systems and prepare samples so that they were "trained" by doing in these areas. We reject this explanation.

Explanation #3. The instrumentalists worked on the microscope to extend the limits of its capability. Because vacuum systems were developed prior to the electron microscope and were adequate for laboratory work, there was no need for the

[17] This judgement is based on reading his book, reference [59].

instrumentalist to improve upon them. Power supplies, although not sophisticated, were adequate (Marton, for example, used batteries for his early high voltage supply). Instrumentalists did work on specimen preparation when it was an important factor in limiting microscope usefulness. For example, Marton developed specimen stains and thin films to support the specimen, and von Ardenne developed a microtome. The microscopes were commercilaized long before the specimen preparation products (see page 50) (e.g., Siemens electron microscope 1939, the ultra microtome, 1954) so that the developments that instrumentalists made in specimen preparation were superceded by other developments by the time commercialization occured.

Careful analysis of the data also shows that instrumentalists did perform innovations that would make the microscope easier to use or more useful. This may be seen by further analyzing the data in the "Usability" column, of table 8 page 36 .

We see from table 10 below, that when specimen manipulation devices are removed from the class of innovations that improve usability, instrumentalists have made a substantial percentage of the few innovations that increase the usability of the microscope. The specimen manipulation devices of commercializers obscure the instrumentalists' contribution in the data in table 8.

Innovations Improving Usability

	Comm.	"User"	Instrumentalist	Total
Specimen Manipulation Devices	(7) 70%	(1) 11%	(1) 11%	(9) 100%
All Other Usability Innovations	(2) 40%	(0) 0%	(3) 60%	(5) 100%

Table 10: All Innovations Involving Usability of the E.M.

Specimen manipulation devices, as innovations, give a distorted view of the activity of instrumentalists. Before 1940 Marton had developed a device to cool his specimen in the microscope but the two specimen cooling devices in our data base of which one was commercialized by Siemens in 1956 and the other by RCA in 1965 are of significantly different design from Marton's devices and each other so that they must be classified as separate innovations of the commercializer.

In summary, instrumentalists' innovations are in the category of devices directly affecting the electron beam in the microscope because innovations in this category were needed to advance the microscope's performance when judged in terms.

"Users"

From Table 8 we see that innovations by "users" are predominantly in the area of specimen preparation. Let us investigate the professional specialization of these people and their affiliations. See Tables 11 and 12 below which show that the majority of users are biologists and their innovations are mostly used in biological specimen preparation.

Primary Area of "User" Interest for "Users" with Innovations Manufactured by Non-E.M. Manufacturers

Biological	Non-Biological	Data Incomplete	Total
(11) 73%	(1) 7%	(3) 20%	(15) 100%

Table 11: $\alpha_1 = .059$

Primary Area of Use of Innovation by "User" When Manufactured by Non-E.M. Manufacturer

Biological	Non-Biological	Data Incomplete	Total
(13) 86%	(0) 0%	(2) 14%	(15) 100%

Table 12: $\alpha_1 = .004$

Compare Table 12 with Table 11

We can conclude that the majority of "users" are biologists and the innovations they perform are in the area of biological specimen preparation. The biologists goals are concerned, naturally enough, with biology. This would also follow from our definition of a "user", a person who is interested in using the innovation as a tool in attaining some goal other than the innovation itself.

We also see from Tables 13 and 14 below that "users" tend to be associated with non-profit institutions. This relationship becomes somewhat stronger if only those innovations produced by non-electron microscope manufacturers are considered.

Affiliation of "Users"

Non-Profit	Comm.	Data Incomplete	Total
(13) 68%	(1) 6%	(5) 26%	(19) 100%

Table 13: $\alpha_1 = .084$

Affiliation of "User" Where Product Made by Non-E.M. Mfg.

Non-Profit	Comm.	Data Incomplete	Total
(11) 73%	(0) 0%	(4) 27%	(15) 100%

Table 14: $\alpha_1 = .059$

Compare Table 14 with Table 13.

One explanation of why most "users" are found in non-profit organizations is that most "users" are biologists and most biological research is done in non-profit institutions, therefore the innovations that occur must come from non-profit institutions. This hypothesis is supported by data from outside the study.

Area of Employment of Biologists in the U.S.[18]

Non-profit	Commercial	Not Listed	Total
76%	10%	14%	100%

Table 15

Commercializers

In order to gain more understanding of the nature of the innovations of commercializers we sub-divide commercializers' innovations by 'area' and by type of manufacturer, that is, electron microscope manufacturer and non-electron microscope manufacturer.

A breakdown into four categories of the innovations developed by commercializers is given below.

E.M. Innovations by Commercializers

Directly Affects Electrons	Usability	Provides Services	Specimen Preparation	Total
(13)	(9)	(9)	(3)	(34)
38%	26.5%	26.5%	9%	100%

Table 16: $\alpha < .02$

[18]Since investigators in material science commonly use electron microscopes, the question should be asked: Why are there few user innovations for devices used in specimen preparation for materials science? That is, why have only biological specimen preparation devices been identified in the data? The answer is most specimen preparation for material science is performed with standard laboratory equipment or with special devices that are built to order and have yet to be commercialized. This accounts for the metal foil samples, which are the most common samples. Replication of the surface of bulk samples is still used but is of less importance. For these samples the same vacuum evaporators and metal evaporation sources used by biologists are used; however, few products are involved. No innovations tied to material science were found.

In Table 17 below, we reanalyze the above data by dividing according to the type of commercializer.

	E.M. Innovations by Commercializers Directly Affects Electrons	Usability	Provides Services	Specimen Prep	Total
E.M. Mfg.	(13)	(7) 24%	(9) 31%	(0) 0%	(29) 100%
Non-E.M. Mfg.	(0) 0%	(2) 40%	(0) 0%	(3) 60%	(5) 100%

Table 17:

The data indicates that electron microscope manufacturers have no innovations in the area of specimen preparation.

Consider the following proposition: while electron microscope manufacturers have no innovation in the area of specimen preparation, the innovations in other areas show no one area predominating.

E.M. Innovations by E.M. Mfg.

Affects Electrons	Usability	Services	Total
(13)	(7)	(9)	(29)
45%	24%	31%	100%

Table 18: Statistical Significance $\alpha < .44$

Due to the large value of we can say that the hypothesis is supported.

Why should this be so? Electron microscope manufacturers do not tend to manufacture or market specimen preparation devices[19] so that it is reasonalbe that they have no innovations in that area.

In the other three areas of innovation where they sell products the commercializer probably does what is necessary to build and sell the product. Instrumentalists are hired as consultants or hired directly as described on page 31. The hired instrumentalists would provide innovations in the area of affecting the electron beam. A certain number of specimen handling devices are needed to be able to sell microscopes (J.C.), see Table 10 page 39.

A detailed look at electron microscope manufacturers innovations in the area of "services," table 19, shows that innovations in the area of electronics dominate here.

There are two probable explanations. First, since all

E.M. Mfg. Innovations
in the Area of "Service"

Electronic	Other	Total
(8) 89%	(1) 11%	(9) 100%

Table 19: $\alpha < .02$

electron microscope manufacturers are large electrical equipment and electronics firms, electronic innovations would be not only in their area of expertise but would be expected by the customers. A second explanation is that the early pump-

[19] The Japanese electron microscope manufacturers may be an exception.

ing systems were close to optimal and there has been little technical advance in the past thirty-five years while very large technical advances were made during that time in electronics. That is, the large number of electronic innovations was due to general technological advancement in that area while the other areas at that time were relatively stagnant.

Cost Reducing Innovations

Of the seventy-nine innovations in the data base, only six were found to be primarily intended to reduce the cost of the electron microscope.

Possible explanations:

1. The magnitude of cost saving achieved by most innovations intended primarily to revise cost is so small that these are not reported individually in the literature or by the people interviewed.

   Without further data this explanation cannot be refuted or supported.

2. The commercializers tend to design for performance (e.g. resolution) and reliability, not for cost. Concerning cost, or from the users point of view, price, the user is probably far more interested in microscope performance since this may affect his work (publications) for which he receives rewards (tenure, professional recognition, etc.) while the rewards for saving money are relatively small (something else may be

purchases in addition to the microscope). In the instance where many users use a microscope in a common facility (this is usually the case) the argument in favor of "buying the best" becomes even stronger than for the single user because there will always be, or may be, users who want the ultimate in performance so that the person making the decision on which microscope to purchase will probably decide to spend more of the institution's money, if possible, and avoid criticism.

The electron microscopes on the market are sufficiently different to be considered differentiated products so that price competition is reduced and competition based on features is increased. Although many government contracts have "Buy American" clauses which would (before 1969) have forced the purchase of an RCA instrument, the "Buy American" restriction can and is circumvented by the purchaser claiming that there is no domestic product technically as good as the foreign unit. This argument is also used to avoid tariffs on foreign instruments which in effect reduces the price (J.C.).[20]

Statistical support for the argument that electron microscope manufacturers tend to design for performance

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[20] Initials in brackets are those of the information source. See Appendix III for names.

rather than cost can be found in the data as follows.

The design intent of manufacturers can be deduced from the use they make of cost reducing innovations. Cost reducing innovations almost always appear in low performance instruments. When they are available, appear in a product, then that product is designed for cost. If there are no cost reducing innovations involved in the product, then the product is designed for high performance.

In this survey, sixteen cost reducing innovations were identified. Of these 75% were on low resolution instruments. Clearly, the electron microscope manufacturers design the high resolution instruments predominately for performance.

All Cost Reduction Innovations

High Resolution	Low Resolution[21]	Total
(4) 25%	(12) 75%	(16) 100%

Table 20: $\alpha \leq .04$

We can also look at who produced the cost reducing innovations.

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[21] Based on three microscopes, each designed for resolution of 100 Angstrom units. The resolution of the High Resolution microscopes varies from about 25 Angstrom units down to about 2.5 Angstrom units depending on the state of the art at the time of design and the acumen of the designers.

All Cost Reducing Innovations[22]

Commercializer	"User"	Instrumentalist	Total
(13) 81%	(0) 0%	(3) 19%	(16) 100%

Table 21: $\alpha_1 \doteq .011$

The sample is actually too small for a Chi Square test of statistical significance. But, the major point is that there are no "user" innovators of cost reducing innovations out of sixteen which is statistically significant with .001.

Possible explanations are:

1. Users are generally not interested in reducing costs but are interested in performance. Our data on innovations performed by users shows that most of these innovations were performed since 1960, during a period of generous government funding. This would also contribute to reduce user concern for costs.

Distribution of Innovations Over Time

Information about the distribution of innovations over time has practical significance for a firm that is looking for product innovations. The time in the life of the product may affect where one should look for innovations--at least in the case of the electron microscope and its related products.

[22] Includes 12 innovations from secondary data base.

The date of the first commercialization of the electron microscope innovations by various groups shows interesting trends. Chart I, on the following page, shows the dates of commercialization for innovations of instrumentalists. The median date is 1947 which is early, in that the number of commercial electron microscopes probably did not exceed 250 at that time.[23]

The first explanation of the large number of instrumentalists' innovations performed early in electron microscope development is that in general most innovations occur in the early life of a product unless there are significant commercial changes in materials and components (e.g. calculators and the advent of integrated circuits). In fact, there were few significant changes in materials and components in the case of the electron microscope. (Some significant material changes have occurred, in particular super-conductors which are used in superconducting electron microscope lenses but so far these have not been commercialized.)

To some extent, in the later history of the E.M., while innovations, according to our definition were sparse, the instrumentalists did work on problems that were not commercialized (e.g. the superconducting lens) or are only beginning to be commercialized (e.g. the high voltage electron microscope which is not included in this study. Less than

[23]Siemens had produced about 30 (Ref. # 85 p. 14) and RCA, the only other commercializer during or before 1947, had not produced 200 EMU electron microscopes until 1949 (Ref. # 85 p. 18). The RCA EMC introduced in 1944 sold about 30 units (J.R.).

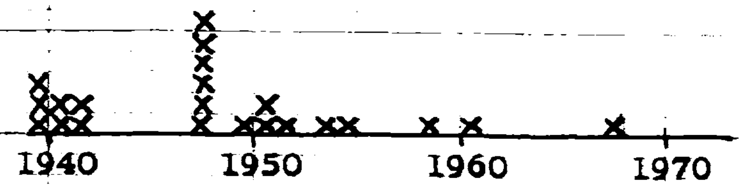

Chart 1: Frequency of Instrumentalists' Innovations

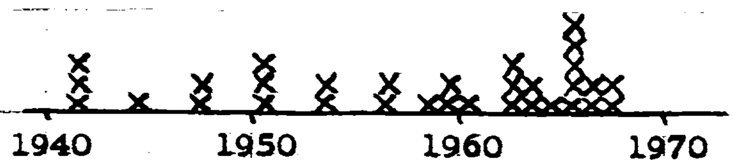

Chart 2: Frequency of Commercializer Innovations

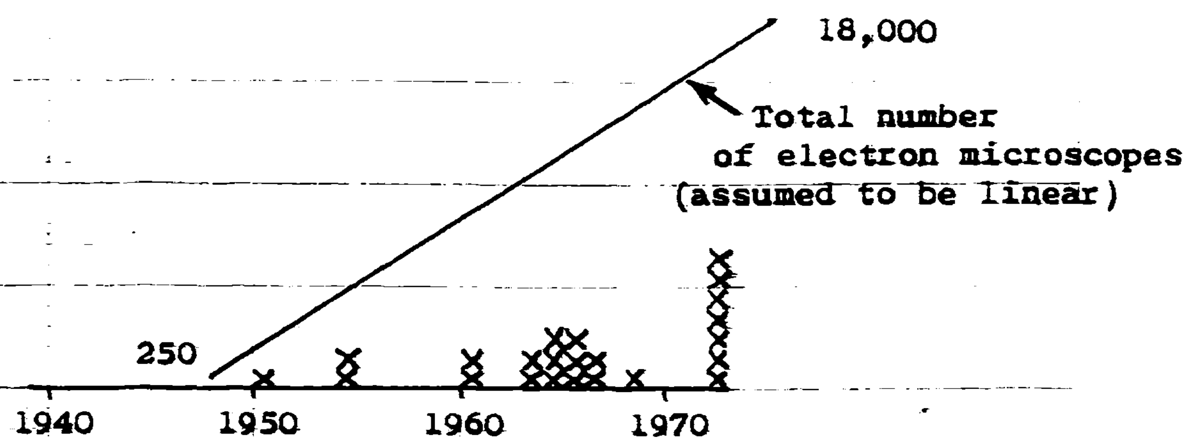

Chart 3: Frequency of "user" innovations

five have been sold in the U.S. to date). Le Poole, for example, was working on a high voltage electron microscope in 1947;[24] Philips has yet to build one commercially.

An explanation for the drop in the number of instrumentalists' innovation over time is that when electron microscope manufacturers hired the instrumentalists they lost their creativity in the corporate environment. This explanation can be tested.

	Innovations		
	Early Period	Late Period	Total
Hired[25]	3	1	4
Not Hired	13	0	13
Incomplete Data	0	2	2
Total	16	3	19

Table 22: $\alpha < .01$

As can be seen from the above table innovations performed by instrumentalists was significantly less in the later period than in the early period, regardless of whether they were hired by manufacturers or not (see Graph I for further information).

The innovations of commercializers show little trend with time although the median is not in the center of the

[24] Marton was not hired since he was only with RCA a few years and had innovations after that time.

[25] See le Poole [50], p. 193.

time period but located about 1960. As in previous analysis of the activities of commercializers, no trend is dicernable. Again, the commercializers seem to do what is necessary to produce the product, probably responding to a number of factors which when taken together show no trend.

The frequency of user innovation shows significant growth with time, the median being located in 1965, eighteen years (more than half the microscope's lifespan so far) after the median of instrumentalists' innovations. It should be kept in mind that user innovations are performed mostly by biologists for use in preparation of biological specimens.

The explanation that it takes users time to become sophisticated in the use of the electron microscope is not convincing considering the length of time involved.

A better explanation, however, is that the growth of user innovation is strongly influenced by the growth of the number of electron microscopes in use. (See Chart I for graph of microscope in use each year). With less than 250 microscopes in use in 1949, the number has risen to an estimated 9,000 microscopes in the U.S. at present and about an equal number abroad.[26]

The larger number of microscopes means a larger number of users. Since only some users produce innovations, we intuitively see that more users will produce more innovations,

[26]Estimated by Donald Johnson, Diamond Knife Manager, DuPont.

even if serendipity is the only mechanism for innovation.

A more important factor may be that a large number of microscopes indicates that there is a large number of users who form a market for the innovations. Recall the discussion on page which pointed out that although instrumentalists did develop devices for specimen preparation, these devices were not commercialized probably because there was no market.

The conclusions of this chapter are summarized in the next and final chapter.

CHAPTER IV: CONCLUSIONS

Introduction

The objective of this study has been to gain some understanding of who performs innovations in the field of transmission electron microscopy and related products. At the same time it was desired to learn where innovations take place and to gather as much other information as possible on innovation in the area studied. We have used the term "innovation" to mean a product or change in a product that is produced and sold for the first time.

Data was gathered on seventy-nine innovations by means of interviews and literature review of the scientific papers in the field. The data base was used to formulate and test various hypotheses about innovation in the field.

Instrumentalists

The instrumentalists are a major source of innovations in electron microscopy. The instrumentalists generally work in a non-profit institution to advance the capabilities of the electron microscope. His innovations predominantly deal with the manipulation of electrons in the microscope itself. His only interest in other parts of the microscope system (e.g. the power supplies) and the devices used in specimen preparation seems to be that they be adequate so that he can work on the factors limiting the optical performance of the microscope.

The innovations of instrumentalists tended to occur in the early life of the instrument when relatively few commercial electron microscopes existed. The reason for this is unclear, although it is suggested that the hiring of instrumentalists away from non-profit institutions by electron microscope manufacturers is not responsible for this decline.

Commercializers

The innovations performed by instrumentalists are transferred to electron microscope manufacturers by the direct hiring of the instrumentalist or by his consulting for the manufacturer. No non-electron microscope manufacturer manufactured the innovations of instrumentalists although such manufacturers appeared to be free to hire an instrumentalist if they wished. It was speculated that because the electron microscope manufacturing companies were large electrical equipment firms and non-electron microscope manufacturers were much smaller, a market situation occurred where non microscope manufacturers were at a disadvantage in selling microscopes or components. These companies specialized in specimen preparation products instead, while electron microscope manufacturers did not sell specimen preparation products, and had no innovations relating to them.

Electron microscope manufacturers have their own employees designing microscopes, in addition to assistance they may have from consultants. Microscope manufacturers performed innovations dealing with manipulation of electrons in the microscope (the instrumentalists specialty), image recording and vacuum systems and specimen manipulation. There was no trend in the amount of innovation in these areas. All the innovations in electronics were performed by microscope manufacturers, although the reason for this was unclear.

Innovations resulting primarily in cost reductions were performed solely by microscope manufacturers. These innovations were found almost exclusively in electron microscopes which were designed to be of lower performance than the usual product line. This provided some support for the hypothesis that microscope manufacturers design for performance rather than cost, except in special situations. It was concluded that electron microscope buyers are insensitive to cost. Unlike the innovations of instrumentalists, the number of commercializers' innovations showed no trend with time.

<u>"Users"</u>

The products of non-electron microscope manufacturers have concentrated in the area of specimen preparation devices. The users were almost all researchers in the biological sciences and they were associated with non-profit institutions.

The number of user innovations has increased with the number of electron microscopes in use. The relationship is attributed to the effect of an expanding market which encourages the commercialization of specimen preparation products.

Future Research

Although there is much more research that could be done on innovation in electron microscopes and related products. We suggest that such research should not be done because a study restricted to the electron microscope only, does not greatly contribute to the understanding of the process of innovation. Research into other instruments or possibly industries would be much more useful. The important questions to be answered are: do other instruments or industries have instrumentalists or some equivalent? If so, do they transfer their innovations to commercializers in the same way as the electron microscope instrumentalists do? Do users of these other products produce innovations? How do they communicate with commercializers?

If no insturment or industry can be found where the answers to the above questions are similar to the answers the electron microscopes and related products, then this study is a story about a unique situation. But if studies of other insturments or industries find similar results to this study, then this study can be used as collateral evidence in building a generalized theory of innovation. At that time it will be more clear as to what the important aspects of innovation in general and the electron microscope and its related products can be studied in more depth.

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APPENDIX I

EARLY HISTORY OF THE ELECTRON MICROSCOPE

This terse history covers the essential events. It is written from a mostly non-technical point of view: the bibliography provides the names of more technical oriented histories. A number of facts obtained from the interviews have "filled out" the history in some spots, especially for those studying innovation.

The first work on the electron microscope was done at the Technical High School in Berlin by Knoll and his student Ruska. They were working on high speed oscilliscopes for the purpose of building devices to better measure the effects of lightning.[27] Their first investigation was into the ways in which you could move an electron beam in a vacuum tube led to their very early model in 1931, (which cannot really be regarded as a microscope) they observed enlargements of the images of apertures.[28]

A few days after Knoll reported his initial results,[29] Rudenberg, who worked for Siemens, a German electrical manufacturer, applied for a patent on the theory of the electron microscope. According to Rudenberg's report on this matter,[30] he was motivated by two thoughts. One, that the optical microscope was limited in resolution to about 1,000 Angstrom units due to the wave length of light, while the electrons had a far shorter wave length, more than a thousand times shorter, and therefore, their resolving power would be a thousand times greater. His second consideration was that he had had a virus illness in his family and that viruses were so small that they could not be seen with the optical microscope, but if a microscope were made using electrons, then viruses could be observed. Rudenberg's covered the basic use of magnetic and electrostatic lenses to form

[27]See Freundlich 29 , p. 185.
[28]See Marton 59 , p. 5
[29]See Mulvey 61 , p. 200
[30]See Rudenberg 69 , p.434

electron optical instruments where electrons took the same part as ligit does in light optics. In that same year, Bruche of the German company AEG[31], also published and reported work in electron optics along lines leading to an electron microscope.

By 1932, Knoll and Ruska had built an improved microscope operating at 65 thousand volts and 120 times magnification. In that year, Von Borries and Ruska patented the magnetic pole piece.[32]

Knoll and Ruska had written some papers on their initial work, and these were read by Marton in Belgium. Marton realized very early that the problems of the electron microscope were problems of getting samples prepared properly, and so he quickly devoted his efforts to the adequate preparation of biological samples. It had been thought that the electron beam would burn the specimen to a crisp or that the vacuum in the electron microscope would destroy the specimen. However, after a year's work, he had demonstrated that biological specimens could be prepared.[33]

In 1933, Knoll and Ruska had improved their microscope so that it was able to exceed the resolution of the optical microscope.[34] However, there seemed at that time to be little promise for the electron microscope so Knoll left the project to work on television. In 1934, Ruska also stopped working

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[31]See Marton 59 , p. 7.

[32]See Mulvey 61 , p. 202.

[33]See Mulvey 61 , p. 203 and Marton 59 , p. 9

[34]See Marton 59 , p. 10.

with the microscope and went into television.[35] But also in 1934, Marton visited Berlin, and visited Knoll and Ruska and some of the people at AEG, and showed them pictures of biological samples that he had taken with the electron microscope. Although he was ridiculed initially, he was gratified that people asked for copies of his picture.[36] In 1935, Marton had built an electron microscope which also was able to exceed the resolution of the optical microscope by a factor of ten.[37] Meanwhile, at Technical High School in Berlin, some biologists and chemists were making use of the Knoll-Ruska microscope.[38] In 1936, Krause was able to demonstrate a resolution of 50 Angstrom units.[39] Due to the interest in applications to biology and chemistry that were shown by Marton and other workers on the Knoll-Ruska instrument, there was in Berlin at that time, a great deal of interest generated in the scientific community. They felt that an electron microscope might be useful.[40] In 1936, von Borries and Ruska tried to promote the development of a commercial electron microscope with the Siemens Corporation and with Ziess. Finally, in early 1937, von Borries and Ruska were hired by Siemens to develop an electron microscope for production. They were joined by Muller and H. Ruska who developed medical and biological application.[41] Their first

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[35] See Mulvey 61 , p. 202 and Marton 59 , p. 19.

[36] See Marton 59 , p. 66.

[37] See Marton 59 , p. 66.

[38] See Mulvey 61 , p. 204.

[39] See Prebus 64 , p. 54.

[40] See Mulvey 61 , p. 205.

[41] See Mulvey 61 , p. 205.

prototype was ready for the end of 1938, and in 1939, Siemens started to produce electron microscopes. The Siemens production microscope contained no novel features beyond what Ruska and von Borries did.[42] In total, Siemens produced about 30 units during 1939 and the early war years.[43]

In 1935, Burton, who had been in Berlin, and had seen the electron microscope work, came to the University of Toronto and transferred the idea of an electron microscope to the Americas. Hall, Prebus and Hillier were working for Burton building electron microscopes. Later, Ladd and V.D. Watson also worked on microscopes at Toronto. In 1937, Marton had demonstrated the first really successful biological microscope picture and in the fall of 1938 left Europe to come to RCA in the United States. With him, he carried the third microscope that he had built.[44]

The microscope technology that was being transferred into the United States and Canada was very important because Hitler had banned the exportation of scientific instruments and publications on certain types of technology.[45] This ban

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[42] See Mulvey 61 , p. 205.

[43] See Wyckoff 85 , p. 14.

[44] See Marton 59 , p. 35.

[45] See Sampson 72 , p. 28. This was not an unwise move. John D. Watson at Toronto and E.F. Fullam at Interchemical Company, and probably others, were using their electron microscopes to assist in the Manhattan Project. According to some historians the building of the Atomic Bomb was originally built to be used against Germany. (See for example, Robert Jungk: Brighter than a Thousand Suns, Harcourt, Brace & World, Inc. N.Y. 1958.)

apparently prevented the export of the Siemens microscope [46] so that if one wanted an electron microscope, one had to build it himself. This indeed was what was happening. After the successful building of an electron microscope at Toronto. Hall went to Eastman Kodak, and there he built another electron microscope patterned carefully after the Toronto unit.[47] Marton at RCA had completed his fourth electron microsccpe by 1940[48]. T. Anderson was at RCA from 1939 to 1941 to develop biological applications for the electron microscope. Also in 1940, Hillier from Toronto went to RCA and General Electric and tried to interest them in building an electron microscope. RCA, who was already interested in building an electron microscope, commercially, felt that if they did not build one, no other company would, and so Hillier was hired in 1940[49]. Hillier quickly built a copy of the Toronto microscope which used a greatly improved vacuum system and electronics designed at RCA. Unfortunately, Marton and Hillier did not get along well personally, and they were building microscopes of a somewhat competitive design. This was especially true in the design of the objective lens. Marton's microscope had a large bore "in gap" type lens while Hillier's microscope had a narrow bore "out-gap" type lens. Marton's design was later used by Philips[50] and Metropolitan

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[46] See Wyckoff 85 , p. 15.
[47] See Hall 25 , p. 285
[48] See Marton 56 , p. 57 and Marton 57 , p. 232
[49] See White 84 , p. 173
[50] See van Dorsten 82 p.40

Vickers.[51]

Before the end of 1941, Marton left RCA and went to Stanford University where he proceeded to construct an additional microscope with a number of innovative features, which was completed in 1944[52]. The Hillier design microscope was known as the RCA type B (EMB) and went into production in 1941. Throughout the war, RCA had a high priority on materials for electron microscopes but still was unable to build their microscopes fast enough to meet customer demands.

The major contribution of RCA, that they added to the basic design of the Toronto type microscope was a very reliable high voltage power supply and regulated lens supply. They also designed a very efficient vacuum system.

In 1944, RCA produced a table model microscope called the EMC.[53] The microscope, however, had only 30 KV electron beam and was unable to adequately penetrate specimens and so burned up. This microscope was rather useless and they only sold about 20 units. In 1950, RCA came out with a table model microscope known as the EMT.[54] This microscope although demanded by consumers initially, only sold about 100 unita.

In 1942, Dr. Simon Ramo and C.H. Backman at General Electric designed an electrostatic electron microscope[55] but because the necessary resources were directed to the

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[51]See Haine 31 ,p. 179.

[52]See Marton 58 , p. 131.

[53]See Zworykin 86 , p. 658.

[54]See Riesner 67 ,p. 1131.

[55]See Backman and Ramo 22 , p.8

development of radar, the microscope was never marketed.

Between 1940 and 1945, experimental electron microscopes were built at Massachusetts Institute of Technology[56], California Institute of Technology [57] and Georgia Institute of Technology[58], but none of these microscopes seems to have contributed to any of the innovations in the field.

In 1944, at the Technical High School at Deft, in Holland, a new microscope with a number of novel features was built. This microscope was used for one month and then dismantled and hid from the Germans, until 1945, when it was reconstructed.[59] The Phillips Company of Holland, in cooperation with le Poole, designed a commercial microscope that was patterned closely after the first one built at Delft.[60]

In England, in 1936, the Metropolitan Vickers Company built their first electronic microscope as a special favor to the Imperial College of Science. This was not a production model.[61] In 1947, they built a second electron microscope, however it is unclear as to whether this was commercially marketed.[62] In 1949, however, they did build a commercial microscope.[63] The designer of this microscope, Haine, then transferred of the Associated Electronics Industries[64], also an English company, where he helped them design another electron microscope.

The Siemens microscopes produced during WW II contained

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[56]See Harvey 38 , p. 929.
[57]See Houston 43 , p. 215
[58]See N.B.S. 63 , p. 8
[59]See Kinder 46 , p. 33
[60]See Reference 3 , p. 179.
[61]See Martin 54 , p. 14
[62]See Liebman 52 , p. 37.
[63]See Haine 31 , p. 179
[64]See Haine 31 , p. 173

the basic features of electron microscopes today. Since then most parts of the microscopes have been significantly improved but the fundamental features have remained the same.

The readers attention should be drawn to a number of facts presented in this brief history.

First: the technology for the first electron microscopes produced had its source in the Technical Institutes and Universities. Many of the improvement innovations to the electron microscope also came from these institutions.

Second: the transfer of the initial electron microscope technology into the commercializing firms took place through the direct transfer of personnel or by consulting: Marton and Hillier to RCA; Ruska and von Barrier to Siemens, le Poole with Philips. The transfer of technology by the movement of personnel in the instrument industry as a whole was reported by Shimshoni, although he only gave cursory attention to the electron microscope.[65]

Third: the electron microscope became a commercial product only after the need was recognized by commercializers. Marton's great contribution was in seeing the usefulness of the electron microscope (in which he was not alone), and solving the problems of applications, particularly problems of biological specimen preparation, and making this information known to potential users through publications and personal

[65] See Shimshoni [76] , p. 83.

contacts. Marton played a critical role in developing interest of potential users whose needs were then transmitted to the commercializing firm Siemens, thus leading to a commercial product.

The importance of manufacturers' being concerned with the needs of potential users was apparently recognized by both Siemens and RCA, because both companies engaged biologists to develop biological applications for the electron microscope before production was begun. (Recall that Project SAPPHO found that successful projects had a better understanding of the customers' needs.)

APPENDIX II

ELECTRON MICROSCOPE MANUFACTURING COMPANIES AND

NON-ELECTRON MICROSCOPE MANUFACTURING COMPANIES.

Electron Microscope Manufacturers

Name	Employees	Sales
AEI	90,000 (1971)	$ 636,000,000
Hitachi	87,000 (1972)	2,400,000,000
Jeol	2,600 (1972)	42,000,000
Metropolitan Vickers	n.a.	n.a.
Philips		
RCA	126,000 (1973)	4,300,000,000
Siemens	308,000 (1973)	4,700,000,000

Non-Electron Microscope Manufacturers

Name	Employees	Now a Subsidiary of
Canalco	40 (1960)	Miles Laboratories (1974)
C.W. French	4	Ebtech (about 1972)
Denton Vacuum	50	
E.F. Fullam	21	
Ladd	36	
Sorvall	450	DuPont (1973)

Parenthesis indicate the year for which figures apply or year of acquisition.

APPENDIX III: PERSONS INTERVIEWED

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School of Madison
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Ross Hall
Washington, D.C.
20037

Dr. Thomas A. Anderson
The Institute for Cancer Research
7701 Burholm Avenue
Philadelphia, Pennsylvania
19111

Mr. J. Blum
DuPont Company
Instrument Products Division
Sorvall Operation
Peck's Lane
Newtown, Connecticut
06470

Lee Cochrine
President, Canalco, Corporation
Rockville, Maryland

Garry Cogswell
IEOLCO
Medford, Massachusetts

Professor A.V. Crewe
University of Chicago
Chicago, Illinois

Mr. Denton
Denton Vacuum Company
Cherry Hill Industrial Center
Cherry Hill, New Jersey

Mr. C.W. French
120 Shoemaker Road
Agawam, Massachusetts

Ernest F. Fullam
Ernest F. Fullam, Inc.
Scientific Consultants
P.O. Box 444
Schenectady, New York 12301

Mr. Rally Hansl
13,930 River Road (Co-founder of Canalco Company)
Patomic Hill,
Maryland
20854

Donald Johnson
Instrument Products; Diamond Knofe Manager
Wilmington, Delaware
19898

Dr. Donald R. Johnson
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Willmington, Delaware
19898

Mrs. Margaret Ladd
P.O. Box 901
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University of Delaware
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APPENDIX IV: LISTING OF INNOVATIONS

INNOVATIONS PERFORMED BY COMMERCIALIZERS

High Frequency High Voltage	1941	(40) p173, 176; (78) p.4; (64)p53; (85)p16; (3)p294, 298; (T.W.), (J.C.)
Feedback High Voltage Supply	1941	(81)p294; 298
Regulated lens Power Supply	1941	(85)p16,24; (64)p58; (40)p173; (66)p377; (81)p299, 300; (T.W.)
High Efficiency Phospos	1944	(86)p664; (36)p209.
Improved RCA Power Supply	1944	(85)p18; (J.R.).
Beam Centering by Magnetic Coil	1947	(82)p42; (51)p47; (66) p370; (3)p179.
Magnetic Objective Stigmator	1947	(41)p307; (42)p61, 48; (85)p15, 18;(J.C.), (E.F.), (J.R.).
Optical Photographic Exposures Meter	1950	(8[illegible])p43.
Self Bias G	1950	(78)p109; (J.C.), (J.R.)
"Non-Airlock" airlock	1950	(67)p1136-37; (82) p43;(52)p39; (J.R.).
Hexpole Objective Stigmator	1953	(39)p29; ;(J.C.), (J.R.)
Magnetic Gun Tilt	1953	(34)p197; (J.C.)
Siemens Cold Stage	1956	(15)p27; (56)p59; (J.C.)
Muvable Condenser Aperture	1956	(J.C.)
Electrostatic, Magnetic Gun Tilt	1958	(34)p196; (82)p42; (32)p357; (J.C.).
Microtome Moter Drive	1959	(74)p122; (J.B.); (K.P.)

Name		Source
Improved Microtome Bearings	1959	(74)p125; (J.B.)
Improved Pole Piece Material	1960	(J.C.), (J.R.)
Double Condenser Hybred	1962	(25)pD-7; (J.C.)
Eight Pole Condenser Stigmator	1962	(J.C.)
Electromagnetic Condenser Stigmator	1962	(J.C.)
Permanent Aperture, Electrical	1963	(J.C.)
T.V. Image Display	1963	(34)p151; (25)p294-297; (J.C.)
Goniometer Stage, Cone Type	1964	(25)pE-7; (J.C.)
Solid State Electronics	1965	(J.C.), (J.W.)
RCA High Temperature Stage	1965	(J.C.)
High Voltage and Lens Stabolization	1965	(J.C.)
RCA Cold Stage	1965	(J.C.)
Philips Rotary Specimen Holdor	1965	(47)p48; (66)p386; (M.L.)
RCA Universal Specimen Chamber	1965	(J.C.)
Double Philips Specimen Holder	1966	(47)p48; (59)p16; (M.L.)
Smooth Sample Imbeding Mold	1966	(C.W.F.)
"Viton" O-rings	1967	(J.C.), (W.L.)
Modular Electronics	1967	(J.C.)

INNOVATIONS PERFORMED BY INSTRUMENTALISTS

Name		Sources
Prefield Condenser Objective	1939	(J.C.)
Mechanical Gun Alignment	1929	(71)p536; (85)p16; (J.C.)
Separable Pole Pieces	1939	(29)p186; (J.C.)
Thermionic Gun	1940	(61)p198; (64)p60; (J.C.)
Biased Gun	1940	(85)p16; (J.C.)
"Outgap" Lens	1941	(64)p56; (J.C.)
Rubber Gaskets	1941	(59)p22, 35; (85)p16; (64)p59; (56)p57; (40) p171.
Three Stage Magnification	1947	(58)p131, 132; (59)p44; (3)p179; (44)p41, 33; (82)p37.
Movable Objective Aperture	1947	(82)p40; (30p179; (49) p43.
Camera Between Projector and Screen	1947	(82)p40; (49)p43.
"Wobbler" Focus	1947	(82)p38; (3)p179; (49)p144; (J.C.), (J.R.)
Diffraction Lens	1947	(61)p105; (82)p37; (59)p44; (49)p41,33.
Sellectable Self Bias	1947	(31)p178; (J.C.)
Single Axis Specimen Tilt	1949	(31)p176; (52)p38; (T.A.), (J.C.)
Scaled up Objective	1950	(59)p37; (82)p39, 40; (57)p32; (31)p179; (28)p132; (J.C.)
Sample Placed Thru Side of Objective Lens	1950	(59)p38; (82)p40; (57) p232; (G.C.)

Name		Sources
Telefocus Gun	1951	(63)p14; (J.C.)
Short Focal Length Objective	1953	(51)p47-57; (28)p12, 17; (82)p33, 39; (57) p323; (67)p1139; (J.C.)
Double Condenser Lens	1954	(34)p165; (59)p41; (59)p132; (J.C.)
Large Angle Magnetic Gun Tilt	1958	(J.C.)
Pin Hole Lens	1960	(80)p141; (53)p753; (52A) p956; (J.C.)
Cold Cathode Gun	1967	(J.C.), (A.C.), (G.C.), (L.W.)

INNOVATIONS OF USERS

Name		Sources
Glass Microtome Knives	1950	(74)p135, (D.J.)
Mechanical Microtome Feed	1954	(74)p132; (J.B.), (K.P.), (J.W.)
Microtome Boat	1954	(74)p131; (K.P.)
Microtome Thermal Specimen Advance	1960	(74)p121 (J.B.)
Microtome Specimen "Bypass"	1960	(74)p121,126,127
Pointed Filaments	1963	(25)pKK-1; (79)p121; (9)p25,27; (C.W.F.), (M.L.)
RCA Condenser Stigmator	1963	(J.C.)
Self Cleaning Aperture, Thin Film	1964	(J.C.), (C.W.F.)
Intergral Pointed Filament	1964	(C.W.F.)
Diamond Microtome Knives	1964	(74)p128; (D.J.), (D.R.J.)
Optional Ion Pump Flanges	1965	(J.C.)
Zenor Diodes in Power Supplies	1965	(25)pE-10; (J.C.)
Vapor Replica Extracter	1965	(47)p30; (M.L.)
Silicon Rubber Imbeding Mold	1966	(47)p22; (M.L.)
Goniometer Stage, Valdre type	1966	(80)p165; (J.C.)
Freeze Fracture Device, Steeve Type	1968	(47)p41; (Denton), (M.L.), (R.S.),(R.W.)
Anti Capilary Tweezer	1972	(C.W.F.)
Thick Specimen Remount Device	1972	(C.W.F.)
Albert's Stain	1972	(64)p697-708; (47) p40; (E.A.), (M.L.)

Name		Sources
Ultra Vilot Curving Chamber	1972	(47)p20; (M.L.)
Evaporation Unit	1972	(M.L.)
Carbon Evaporation Shield	1972	(M.L.)
Freeze Fracture Device, Bullivant Type	1972	(47)p35; (Denton), (M.L.), (R.S.),(R.W.)