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THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

THE MICROSCOPE AND NINETEENTH CENTURY EDUCATION

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

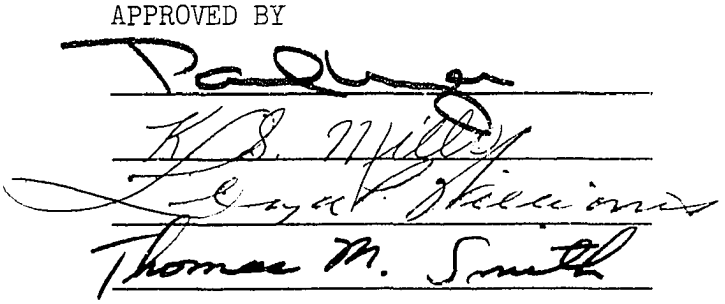
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Norman, Oklahoma

1966

THE MICROSCOPE AND NINETEENTH CENTURY EDUCATION

APPROVED BY



DISSERTATION COMMITTEE

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Barbara Roads Milacek

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THE MICROSCOPE AND NINETEENTH CENTURY EDUCATION

CHAPTER I

INTRODUCTION

Today the microscope is considered an important tool in science education. It is an essential item in the school laboratory. Not only is the microscope used as a tool in teaching science, but also the use of the microscope is taught in special micro-technique courses in order that the microscope can be effectively used as a tool in laboratory investigations. Microscopes are considered necessary even in the elementary and secondary school science classrooms. They are extensively advertised in school science journals, and their use is encouraged.

Yet the microscope has not always been considered an essential tool in teaching science. Presumably the microscope has long been considered a luxury in the school room.

It is difficult to imagine the teaching of science without the use of the laboratory and its associated equipment. However the advent of laboratory teaching is relatively recent. In fact, the teaching of courses concerning science is also relatively recent.

In comparison to the relatively recent advent of the microscope into the classroom, this instrument has a long and fascinating history. It has been around in one form or another for several centuries. It

has been a popular tool for scientific amusements as well as an important tool in scientific achievements. In the seventeenth and eighteenth centuries, many laymen pursued a self-study of natural objects with the microscope.

Meyers stated that the appeal of the microscope as well as the telescope was a romantic one which tantalized the imagination of seventeenth and eighteenth century mankind. According to Meyers one reason which encouraged a study of nature was the belief that a familiarity with sciences would fill a person with love and esteem for God.[1] "It seemed to be axiomatic with the eighteenth century that if technicians would provide England with a sufficient supply of microscopes, that nation would reap a plentiful harvest of good Christians."[2]

In 1746, a book appeared written by a mathematical, philosophical, and optical instrument-maker, George Adams. The purpose of his book was to explain microscopes, his own microscopes, and to explain how and what to observe under them. In other words, this was a book popularizing the use of the microscope by interested laymen. Adams stated:

> If then a serious Contemplation of the Works of God, may justly be consider'd as an excellent Kind of Knowledge, and worthy of our Pursuit; and if all those Works, though different in Degrees of Splendour, are still perfect; it is hoped, that an humble Attempt to improve, and encourage the study of any Branch of Natural Philosophy, will not be unacceptable to the Publick. And since the Knowledge of the Microscope has always been look'd upon as no inconsiderable Branch of Natural Philosophy, and as that Part of it

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[1]Gerald Dennis Meyer, The Scientific Lady in England 1650-1760: An Account of Her Rise with Emphasis on the Major Roles of the Telescope and Microscope (Berkeley: University of California Press, 1955.), p. 1.

[2]Ibid., p. 87.

> has more particularly fallen within the Compass of the Author's Studies, he has ventured to make it the Subject of the following Treatise; a Subject, which has so often employ'd the most learned Men, that it can hardly stand in Need of an apology for the Choice of it. . . . The Microscope is an Instrument so curious and entertaining, and so generally esteemed amongst the learned Part of the World, that one great Reason of its being so much disregarded by Men of Leisure and Fortune, must be owing to the Difficulty of using some of those, which have been nitherto invented. Besides, many persons have neglected the Microscope, from an apprehension, that a good Degree of Knowledge in Opticks would be necessary to their Understanding even the experimental Part of it; whereas nothing more is really required, than good Eyes, good Glasses, and a well-constructed Instrument; with these Helps, a common Understanding, and a little Practice, will be sufficient to carry us through this Branch of Natural Philosophy.[1]

Henry Baker also published two books in the middle of the eighteenth century. The purpose of both of these books was to spread knowledge about the use of the microscope and to encourage the use of it by people to increase their knowledge of nature.[2]

During the seventeenth and eighteenth centuries, it was considered a very proper pastime for women also to study nature with the microscope. According to Meyer, the telescope and microscope exerted a strong and direct appeal to the feminine mind.[3] The microscope especially became a delight of laymen (particularly women) because it was small, portable, cheap, and relatively easy to use.[4] The microscope was popular among women of the bourgeoise as well as the nobility.[5]

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[1]George Adams, Micrographia Illustrata or The Knowledge of Microscope Explain'd: Together with an Account of a New Invented Universal, Single or Double Microscope, Either of which is capable of being applied to an Improv'd Solar Apparatus (London: Printed for and Sold by the author, 1746), p. 6.

[2]Henry Baker, Employment for the Microscope in Two Parts (London: R. Dosley, 1753), passim. and Henry Baker, The Microscope Made Easy (3rd Edition, London: R. Dodsley, 1744), passim.

[3]Meyer, p. vii. [4]Ibid., p. 95. [5]Ibid., p. x.

Instrument makers took the opportunity to increase their business by further stimulating the interest in the microscope and the study of nature among women. They wrote and illustrated popular books and gave scientific lectures to which ladies were invited.[1]

One instrument maker, Benjamin Martin (1704-1782) who was also a member of the Royal Society, strove to interest ladies and young people particularly in the microscope. In his The Young Gentleman and Lady's Philosophy he related much scientific information by use of a popular dialogue. At the same time he made mention of the many kinds of microscopes and how they were used. In this story a young man who was attending college undertook to teach his interested sister all about science. He gave his sister single microscopes, compound microscopes, and even one in a shagreen case.[2]

Between 1747 and 1766, a periodical, The Female Spectator, was published by scientific ladies for scientific ladies, and it included much about microscopical observations and the study of natural history. It was a very popular periodical both in England and America.[3]

To illustrate further the popularity of the microscope among the people of the late seventeenth and early eighteenth century, it should be mentioned that even plays were presented about girls who loved microscopy. One such play was The Basset-Table written in 1705 by Susannah Centlivre.[4]

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[1] Ibid., pp. 36-37.

[2] Benjamin Martin, The Young Gentlemen and Lady's Philosophy (London: W. Owen, 1763), passim.

[3] Meyers, p. 82.

[4] Ibid., pp. 96-97.

Need for Study

In spite of the early popularity of the microscope and also the scientific achievements made with the microscope, the use of the microscope within the colleges and universities has been seemingly slow. Some who have written on aspects of the history of science education have indicated the need for studies illuminating the development of science education, the content of courses, the methods of teaching the courses, the equipment used in teaching the courses, and others.

Cohen, a historian of science, stated: "A well-informed study of the growth of science teaching and research at any institution of higher learning during the period extending roughly from 1700-1837 would be of great value if it exhibited the nature and development of the facilities for instruction (the apparatus or tools) . . . ."[1]

Bell also indicated a need for the study of science education in American institutions of higher education. He stated: "And we want to know how science was taught. What laboratory equipment was there? Were students required or permitted to perform experiments, or was everything illustrated for them only by demonstrations by the professor?"[2]

Kuslan noted in his study of the teaching of science in normal schools that the provision, or lack, of materials for science in the

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[1]I. Bernard Cohen, Some Early Tools of American Science (Cambridge, Mass.: Harvard University Press, 1950), p. 3.

[2]J. Whitfield Bell, Jr., Early American Science Needs and Opportunities for Study (Williamsburg, Va.: Institute of Early American History and Culture, 1955), p. 25.

normal schools would alone be a fit subject for a dissertation. He noted that many materials are available for such a study.[1]

The Problem

Because the microscope has had a long and fascinating history, because it has been responsible for many scientific achievements and the consequent advancement of the biological sciences, because it had been popularly used for several centuries, the incorporation of this tool into the teaching of science might possibly help shed light on the general development of the teaching of science, its methods, and philosophies.

The problem of this paper, then, will be to survey the evolving use of the microscope as a tool in science education and to relate this increasing use of the microscope to the changing methods of teaching scientific courses, to the changing content and emphases of the scientific courses, and to the prevailing philosophies of education.

Assumptions

To begin with, it is helpful if some artificial divisions or periods of science education can be established. Louis Kuslan arbitrarily divided science teaching into divisions according to the methods of science teaching.[2] These methods include the teaching of science by recitation, by the lecture-demonstration method, by the analytical-

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[1]Louis I. Kuslan, "Science in Selected Normal Schools of the 19th Century" (unpublished Ph.D. dissertation, Yale University, 1954), p. 679.

[2]Ibid., passim.

objective method, and by the laboratory method. For the purposes of this paper, the assumption of these same divisions will be made. The use of the microscope will be classified according to Kuslan's last three arbitrary divisions (lecture-demonstration, analytical-objective method, and laboratory teaching) to ascertain the role of the microscope and to ascertain under which method it was incorporated to the fullest extent and perhaps why this was true.

Limitations

Certain limitations have been set for this study. First, it has been limited primarily to the nineteenth century. Too, it has been limited to higher education. Also, it has been further limited to American higher education. Finally, the University of Oklahoma History of Science Collection and other rare books and periodicals have been available for this study, but primary materials such as notebooks and lecture notes have been unavailable.

Nineteenth Century

To furnish a background for the increasing use of this tool during the nineteenth century some examples of the use and possession of microscopes by institutions during the eighteenth century have been included. The nineteenth century has been chosen because this seems to be a period of great change in education; a change in the basic philosophy of education began to occur which allowed changes of content of the courses and the methods of teaching, as well as making possible an increasing number of courses.[1]

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[1]R. Freeman Butts, The College Charts Its Course (New York: McGraw-Hill Book Co., Inc., 1939), passim.

The nineteenth century was the period of the establishment of new kinds of schools and institutions -- particularly technical schools and scientific courses such as Rensselear Polytechnical Institution, Lawrence Scientific School, and Sheffield Scientific School. Scientific interest was growing among the people; as scientific and technological advances were being made, people were becoming aware of science and technology. These developments would seem to indicate a growing place for the microscope within education.

The nineteenth century also was the period of the increasing influence of the German university on the American educational system.[1] At the beginning of the nineteenth century, the American institution of higher education was patterned after the English colleges. One determined course of study was presented--the study of the classics (Latin and Greek), mathematics, and a few offerings in natural philosophy.

A classical course of study was the valued vehicle for achieving aims of mental discipline. This philosophy is based on faculty psychology which purports the idea that certain courses developed intellectual powers and expanded the mind's power.[2]

The intellectual ability of students was emphasized rather than the amount of knowledge which they might acquire. Certain subjects (those listed above) were believed to be the ones which best developed intellectual power, and it was believed those courses would serve as a preparation

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[1] Ibid., p. 203.

[2] The ideal of mental discipline is represented by the Yale Report of 1828.

for any type of life.[1] Therefore no more was included in the curriculum than could be mastered in four years. Subjects were chosen for their value in developing intellectual ability; some subjects might be added for their value in imparting knowledge (such as the courses in natural philosophy) but never for their practical utility.[2]

Partly for this reason separate "parallel" courses and independent technical schools were established to teach the science courses which the utilitarian and democratic society began to demand. Rensselaer Polytechnic Institute, Worcester Polytechnic Institute, and the Massachusetts Institute of Technology were established in complete isolation from any existing college. Scientific schools such as the Sheffield School at Yale, the Lawrence Scientific School at Harvard, and the Chandler Scientific School at Princeton were set up alongside the traditional colleges as parallel courses of study to care for the "practical minded students."[3]

Important intellectual movements influenced the theory and practice of higher education during the nineteenth century. Butts classified these intellectual movements as: (1) the continued achievements in the field of physiological and biological science; (2) the formulation of the peculiarly American philosophy of pragmatism; (3) the beginnings of an experimental psychology which threatened to destroy the theoretical bases of mental discipline; and (4) the highly

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[1]Butts, pp. 118-119.

[2]Ibid., p. 127.

[3]Ibid., p. 129.

controversial discussions concerning in general the nature and functions of higher education and concerning in particular the relative advantage of the classics and literature versus science.[1]

Throughout the nineteenth century there occurred an increasing influence of the German universities on American higher education. The elective system began to emerge and was realized during the nineteenth century. This plus the intellectual movements listed above made it possible to present a greater number of courses. Scientific courses, such as those taught in the German universities, were introduced as was the German method of teaching these courses--the use of the laboratory. All of these things would seem to provide further stimulus for the increasing use of the microscope during the nineteenth century.

Also during the nineteenth century, the improved microscope made it possible for natural historians to evolve into scientists; that is, with the aid of the microscope many new hypotheses about natural phenomena could be made. The fields of histology, microscopical pathology, bacteriology, and embryology came into being. Because of the emergence of the elective system, these courses could be added to the curriculum. They, in turn, would surely stimulate the use of the microscope.

Also during the nineteenth century, there was a growing interest in the microscope as an essential tool in scientific investigations. This was probably due to the improvements made in the microscope and the consequent scientific advances as was stated above. Allen stated:

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[1]Ibid., p. 161.

> The decade from 1870 to 1880 witnessed the birth of many amateur microscopical societies in America. They had already become popular in England. Enthusiasm ran high. They issued journals and other publications as outlets for new information concerning things microscopic. We owe these societies much gratitude, for they preceded the general introduction of the microscope into the classroom, and they were the principal sources of information and training in the use of the instrument.[1]

Therefore the presence of these societies and journals probably also encouraged the use of microscopes in the teaching of science courses.

The nineteenth century witnessed both educationally changing conditions and also scientifically changing conditions which should make that time right for the increasing use of microscopes in the teaching of science.

Higher Education

This study is limited to higher education because it has been shown in other studies that the teaching of science was just beginning in the elementary and secondary levels at the end of the nineteenth century. Science was generally taught in the highschool mostly through the use of textbooks until the early years of the twentieth century.[2] Natural science was seldom taught in the elementary school.[3] After 1800, when C. E. Bessey's botany textbook appeared, the "new" botany spread emphasizing the morphological and physiological study of botany. Actual

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[1] R. M. Allen. The Microscope (New York: D. van Nostrand Company, Inc., 1940), p. 12.

[2] Victor H. Noll, "Science Teaching on the College Level," ed. Guy Montrose Whipple, A Program for Teaching Science, Thirty-First Yearbook of the National Society for the Study of Education, Part 1 (Chicago: National Society for the Study of Education, 1932), p. 307.

[3] Kuslan, p. 247.

laboratory work in botany became something of a fad in the few secondary schools able to equip a laboratory with the vital microscopes and dissecting tools. However, on the whole, few high schools had provided laboratories for botany or zoological instruction.[1] Therefore the attempt to study the use of the microscope at the elementary and secondary school levels will not be pursued.

The area of higher education will include the colleges, the developing universities, separate scientific institutions, the "parallel" science courses such as Sheffield and Lawrence, medical education, and normal school education.

American Higher Education

American higher education primarily will be surveyed to ascertain the role of the microscope in science education. Because our education was influenced by developments in foreign, particularly German, education, the increasing role of the microscope in England, Germany, and France, will be reviewed. Many of the educators in the nineteenth century American colleges and universities had studied in Europe, and therefore the influence of these countries is of importance. However, the primary emphasis of the present study will be placed on American institutions.

Available Materials

Another limitation to this study is that primary materials such as students' notebooks, professors' lecture notes, and local records

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[1] Ibid., p. 269.

have not been available for perusal. Therefore, this study will be a survey to gain an overall view of the emerging role of the microscope in relation to the changing philosophies and methods of education in American education. However access to many rare science books of this period, biographies, histories of various institutions, all volumes of Barnard's American Journal of Education, all volumes of Silliman's American Journal of Arts and Sciences, and the extensive University of Oklahoma History of Science Collection have been made available for purposes of this study.

Review of the Literature

Although much has been written about microscopes in general, the history of the microscope, and micro-technique, very little has been written about the use of the microscope as a tool in teaching science. Although, as was previously stated, a need exists for the study of tools used in teaching science, this has seemingly remained an unexplored area of research.

I. B. Cohen's book, Some Early Tools of American Science, is a survey of the instruments and mineralogical and biological specimens which were used at Harvard primarily during the eitheteenth century and the chemical equipment which dates from the early years of the nineteenth century. A good account is given of the history of the teaching of science at Harvard, the philosophical apparatus, chemistry instruction, and biological and museum specimens. An extensive account of the microscopes owned by Harvard during the eighteenth century and a few notes on the use of the microscope during that period are available. Cohen's study differs from the present study in that it is limited to

one institution, Harvard; it is limited to the eighteenth century; and, as it pertains to microscopes, it contains lists of inventories of microscopes owned by that institution. This book is a valuable aid to anyone studying the history of science education in American institutions.[1]

Another study in the history of the teaching of science is the chapter entitled "The Part Played by the Microscope" in Smallwood's Natural History.[2] A thorough review of microscopes in early American institutions is presented. This book is unique in that it relates the use of the microscope to the teaching of natural history. Smallwood's study is limited primarily to the eighteenth century.

Lorande Loss Woodruff, a biologist and microscopist, wrote on the advent of the microscope at his own institution, Yale. This article is an exposition relating when various microscopes were added to the philosophical apparatus during the eighteenth century. Although little is given about the use of these microscopes, this is a helpful article in establishing a background for use of the microscope in the nineteenth century.[3]

One of the best studies on the history of the teaching of science is a Ph.D. dissertation written by Louis I. Kuslan. His study was limited to the teaching of science (during the nineteenth century) by ten normal schools located in New England. This study encompassed

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[1]Cohen, passim.

[2]William Smallwood and Mabel Sarah Coon Smallwood, Natural History and the American Mind (New York: Columbia University Press, 1941), pp. 195-214.

[3]Lorande Loss Woodruff, "The Advent of the Microscope at Yale College," American Scientist, XXXX (July, 1943), pp. 241-245.

all aspects of the teaching of the biological sciences; therefore much information about the use of the microscopes in those particular schools was available. Chapters on the teaching of elementary and secondary school science were also included. Kuslan's investigation was different from the present study in that it was limited to ten normal schools, and it covered all aspects of the teaching of science rather than the investigation of one certain tool.[1]

Several other studies have provided much information about the history of science teaching in the United States which helped establish the necessary background for this present study. Some of the studies which were especially helpful were Hollisters' "Development of the Teaching of Introductory Biology in American Colleges,"[2] Glover's "Development of the Biological Sciences in Teachers Colleges of the Middle West,"[3] and Teaching Science in the Schools by Downing.[4]

Conclusion

The problem of this study will be to survey the increasing use of the microscope as a tool in teaching science in relation to the changing curricula to the methods of teaching science, and to the philosophies of education.

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[1] Kuslan, passim.

[2] Paul Livingstone Hollister, "Development of the Teaching of Introductory Biology in American Colleges " (unpublished Ph.D. dissertation, George Peabody College for Teachers, 1939), passim.

[3] Thomas Harold Glover, "Development of the Biological Sciences in Teachers Colleges of the Middle West" (unpublished Ph.D. dissertation, George Peabody College for Teachers, 1940), passim.

[4] Elliot Rowland Downing, Teaching Science in the Schools (Chicago: The University of Chicago Press, 1925), passim.

This study will be limited to the nineteenth century. It will be a study primarily of American institutions of higher education.

Because the history of the evolution of the microscope as a tool in scientific investigations is fundamental to the use of the microscope as a teaching tool, a brief history of the microscope will be presented. As the availability of microscopes is very important to its being used as a tool in educational institutions, the manufacture of microscopes and their availability during the nineteenth century will also be investigated.

Although this study is primarily limited to American institutions of higher education, the foreign universities provided great influence on the American institutions. Their philosophies and methods of education were studied and adapted to the American colleges and consequently universities. Therefore, it is appropriate to review the use of the microscope as a tool in teaching science in the European universities. The German, English, and French universities in particular will be examined since they probably exerted the most influence on the American institutions.

The role of the microscope in American medical colleges will be surveyed as the subject matter taught in medical schools would seem to indicate that they would be the logical institutions for the incorporation of the microscope.

The advent of the microscope into the American colleges during the eighteenth century will be reviewed to provide the necessary background for the role of that instrument in nineteenth century institutions. The philosophies of education, the introduction of scientific schools, the

research and teaching of biological sciences, and the establishment of normal schools and object teaching will also be examined. Because the methods, philosophies, and course content are all so inextricaly intertwined both with each other and also with the use of the microscope, the examples of the use of the microscope will be investigated according to the three main methods of teaching science: the lecture-demonstration method, the analytical-objective method, and the laboratory method.

CHAPTER II

THE EVOLUTION OF THE MICROSCOPE

Before investigating how and when the microscope was introduced into the classroom as a tool in the teaching of scientific subjects, the development of the microscope as an instrument should be reviewed. The microscope was not suddenly invented one day and placed in the classroom the next. In fact, as with many other technical tools of the scientists and investigators, the exact beginning of the microscope is rather obscure. Who invented the first microscope continues to be an unanswered question.

Even after its first appearances, the microscope was hardly the same instrument as was known in the nineteenth century by scientists, educators, and students. Therefore it is necessary to review the evolution of the microscope from the advent of the first ones to the microscopes of the nineteenth century.

First the meaning of the word "microscope" should be clarified. For the purposes of this paper, the definition presented by Gage will be used. "The microscope is an optical apparatus with which one may obtain a clear image of a near object, the image being always larger than the object."[1]

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[1]Simon Henry Gage, The Microscope: An Introduction to Microscopic Methods and to Histology (11th ed.; Ithaca, New York: Comstock Publishing Co., 1911), p. 1.

Pre-Microscopic Lenses

Although the generally accepted time of the appearance of the microscope is set around the end of the sixteenth century, the phenomenon of magnification and the ability of lenses and water to magnify were known and appreciated by the ancients and natural philosophers of the middle ages. Clay and Court quoted passages from both Pliny and Seneca depicting their knowledge of burning glasses and the magnifying properties of some glasses and water.[1]

The general knowledge of lenses and magnification by the ancients was summarized by Pieter Harting in his Das Mikroskop written in 1859. Clay and Court translated that summary as follows:

> "(1) The Ancients were in possession of the art of cutting transparent and opaque stones.
>
> "(2) They sometime gave these the approximate forms of concave and convex lenses.
>
> "(3) They could do glass-blowing and understood the arts of glass-melting and glass-grinding.
>
> "(4) They used spherical and lens-shaped glasses as burning glasses.
>
> "(5) They had observed the magnification of objects placed in a bulb filled with water.
>
> "(6) There appears no certain mention of magnification by a lens-shaped or spherical glass, but one must consider it most unlikely that this property could have escaped the notice of those who handled such glasses."[2]

---

[1]Reginald S. Clay and Thomas H. Court, The History of the Microscope Compiled from Original Instruments and Documents, up to the Introduction of the Achromatic Microscope (London: Charles Griffin and Company, Limited, 1932), p. 2.

[2]Ibid., p. 3, quoting Pieter Harting, Das mikroskop [Theorie, gebrauch, geschichte und gegenwartiger zustand desselben, von P. Harting], Deutsche originalausgabe, vom verfasser revidirt und vervollständigt. Aus dem holländischen übertragen von Dr. Fr. Wilh. Theile (Braunschweig: F. Vieweg und sohn, 1859), p. 3.

Alhazen and Roger Bacon, who lived in the tenth and thirteenth centuries respectively, both wrote of the magnifying powers of curved glass.[1] Spectacles were invented around 1300, and Clay and Court believed their invention led to that of the microscope and telescope.[2]

The Emergence of the Microscope

As was stated above, details of the actual invention of the microscope are largely unknown. It appears that it could have been developed during the same time period by several men interested and engaged in the making of other optical instruments such as spectacles and telescopes.

At the present time, writers on the history of the microscope seem to agree that the emergence of the first microscopes probably occurred between 1590 and 1621. It was probably developed both by the Jansens of the Netherlands and by Galileo in Italy during this period.

Several who have written on the history of the microscope have accredited its invention to the Jansens of Holland around 1590. Queckett states "But, notwithstanding all of the above conflicting statements, the credit of the invention of the compound microscope is given (in this country at least) to Zacharias Jansen, in 1590."[3] Disney stated that Van Swinden and G. Moll of Utrecht who wrote in 1830 believed that either

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[1] Ibid., pp. 4 & 5.

[2] Ibid., pp. 5 & 6.

[3] John Queckett, A Practical Treatise On the Use of the Microscope Including the Different Methods of Preparing and Examining Animal, Vegetable, and Mineral Structures (London: Hippolytie Balliere, 1848), p. 3.

Hans or his son Zacharias Jansen invented the microscope about 1590.[1]

Disney also quoted the conclusions written by Pieter Harting in 1866:

> 1. The compound microscope had been invented in Middleburg certainly several years before 1610. 2. The first microscope made by Janssen certainly could have not come into possession of Prince Maurice before 1584, nor the second into possession of Archduke Albert before 1596. 3. There is much reason for thinking that the invention should be assigned to 1590.[2]

It seems from Disney's writings that he also tends to believe that the invention of the microscope should be attributed to the Jansens.[3]

The evidence on which Disney bases his decision is presented in a book written by Pieter Borel (1620-1689) in 1655, entitled De vero telecopii inventore. On page thirty-four is a letter written by William Borel (1591 - ?) who was the Dutch Ambassador at the court of Louis XIV. According to William Borel's letter in Pieter Borel's book, William Borel had known the Jansens all of his life and had been a playmate of the son, Zacharias. According to Disney, William Borel stated that John and his son Zacharias were the first to invent the microscope which was offered to Prince Maurice, Stadtholder and Commander in Chief of the army of Federated Belgium. The Jansens supposedly received some payment

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[1]Alfred N. Disney (ed.), Origin and Development of the Microscope, as Illustrated by Catalogues of the Instruments and Accessories, in the Collections of the Royal Microscopical Society, together with Bibliographies of Original Authorities (London: The Royal Microscopical Society, 1928), p. 89.

[2]Disney, p. 97, quoting Pieter Harting, Das mikroskop. [Theorie, gebrauch, geschichte und gegenevärtiger zustand desselben von P. Harting], 3 bd. Geschichte und gegenwärtiger zustand des mikroskopes servie der hülfsapparate bei mikroskopischen untersuchunge. Deutsche originalausgabe vom verfasser revidért und vervollstandigt. Hrsg. von Dr. Fr. Wilh. Thiele . . . 2. wesentlich verb. und verm. aufl. (Braunschweig: F. Vieweg und sohn, 1866), p. 30.

[3]Ibid.

for the instrument. A similar microscope was afterwards offered by them to Albert the Archduke of Austria, Supreme Stadtholder of the Belgium Kingdom.[1]

William Borel saw this last mentioned microscope in 1619 when it was in possession of Cornelius Drebbel (1572-1633) as is related in the following quotation which was written in a letter in 1655, from William Borel to his cousin Pieter Borel:

> When I was ambassador in England, in the year 1619, Cornelius Drebbel, a Dutchman from Alkmaar, familiar with many of Nature's Secrets, who was employed as a mathematician in the service of James I and was a friend of mine, showed me the instrument which the Archduke [Albert] had given him as a present, namely, a microscope by that same Zacharias. It was not equipped, like the ones one sees now, with an insignificant little tube, but with one about a foot and a half long, the tube itself being of gilded legs rested on a round ebony disc. On this disc could be placed little particles of dust or other tiny objects, which could then be looked at from above, their forms being then magnified to an almost miraculous degree.[2]

A microscope, which was evidently quite similar to the one described above, is the subject of a letter written by Nicolas-Claude Fabride Peiresc (1580 - ?) to his brother concerning a microscope he had seen on May 22, 1622. Peiresc related in the letter how he had viewed through a "lunette" a mite which looked as big as a fly. He credited the invention to Cornelius Drebbel. Peiresc viewed this microscope at a demonstration in the chamber of Maria de Medici, the Royal Mother. Jacob Kuffer who was the brother of Drebbel's son-in-law, Abraham Kuffer, gave the demonstration.

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[1]Disney, p. 91.

[2]Gerrit Tierie, Cornelis Drebbel (Amsterdam: H. J. Paris, 1932), p. 54. Tierie dated this letter as written in 1655.

Peiresc described the microscope as being the length of a travelling quill case and the diameter of a wrist and as being made of gilded brass. It was assembled in three pieces. At one end was a small funnel painted black in which there was a little hole about the size of a small nail to look through. At two fingers distance from the little hole was a fairly small glass sphere. This would have been the objective. Peiresc also described the ocular which was a half of a globe of glass the size of a small cherry which was neither truly convex nor oncave. This ocular was fixed in the extremity of a smaller tube about a third in diameter of the one mentioned above and about the length of a little finger.[1]

Of particular interest is the part of the description which matches Borel's description of Drebbel's microscope. Peiresc stated that the instrument was encased with a circle of gilded brass and was supported by three small feet which rested on a small flat plate. Between this flat plate and the lens, there was a small black round plate which was mobile. The objects were placed on this. Peiresc noted that the object could be seen in reverse, in such a way that the animals progressed to the right to see them with the plain eye; with the microscope they seemed to be walking to the left.[2]

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[1]Pierre Humbert, "Peiresc et le microscope," Revue d'Histoire des Sciences et de leurs applications, IV (Avril-Juin, 1951), 154-58. This is a French translation of a manuscript found in Folios 407-08 of the 1774 collection of the Library of Ingembortine de Carpentras. Copies of this manuscript are found in the National Library in Paris and at the one in Dijon. Peiresc was a humanist who studied history, archeology, astronomy, geology, and zoology. All of his adult life he was a counselor to the provincial parliament.

[2]Ibid., p. 155.

Tierie stated that on August 14, 1622, Peiresc sent two of the microscopes to Rome to the Pope. "At first however the Romans could not make them work properly. After Galilei brought his microscopes to Rome in May, 1624, (one concave and one convex lens) success was achieved in making Drebbel's microscopes work."[1]

One more piece of evidence which points to the Jansens as being the probable inventors of the microscope is presented by Disney who stated that there is a compound microscope in the museum of Middleburg, which according to the townspeople was made in 1590. Evidently the only indication of its date is the word of the people of Middleburg where the Jansens lived. This microscope consists of three parts; two smaller tubes fit into one larger middle tube. The length and the width of this microscope correspond to the length and width of the microscopes described by Borel and Peiresc. There the coincidence ends. Judging from the descriptions of both Borel and Peiresc, Drebbel's microscope had much greater magnification than the Middelburg microscope whose highest magnification was nine diameters.[2] Perhaps the Middleburg microscope was made prior to the microscope which was given to the Archduke of Austria and then to Drebbel.

Another part of the Jansen story which is unclear is the mix-up of the names of the father and son. As has been seen, the invention of the microscope is dated as 1590. William Borel in his letter to his cousin, Pieter, attributed the invention to Zacharias Jansen who was, according to Disney, a playmate of William Borel.[3] He also stated that

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[1]Tierie, p. 57. [2]Disney, pp. 102 & 103.

[3]Tierie, p. 54 and Disney, p. 91.

John was the father, and Zacharias was his son.[1] William Borel was born in 1591. If Zacharias was a contemporary of William Borel, it is doubtful that he could have invented the microscope in 1590, as is stated by Harting and Quekett.[2,3] However, Pieter Borel in his book cited certificates which had been signed by Middleburg authorities in March 3, 1655, stating that Zacharias and his son John Jansen had lived in Midleburg during the late sixteenth and early seventeenth centuries.[4] Since William Borel wrote the letter in 1655 about incidents which had occurred about sixty years earlier when he was between one and nine years of age, perhaps he confused names. This inconsistency in names and in the number of years involved before actual dates were recorded is pointed out to show both the nebulousness of the situation and the reason why it is difficult to state who invented the first microscope.

During the same period, Galilei Galileo (1564-1642) also invented a microscope by reversing his telescope. It is known that he had done this before 1610, because in that year, John Wodderborn, a pupil of Galileo, wrote:

> I heard the author himself [Galileo] narrate to that noble philosopher, the most excellent Signor Cremonius, various things worthy to be known, and among others how he perfectly distinguished with the telescope [perspicillum] the organs of motion and of sense in the smaller animals, but especially in a certain insect which has each eye covered by a rather thick membrane that is nevertheless

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[1]Disney, p. 91.

[2]Ibid., p. 89.

[3]Quekett, p. 3.

[4]Disney, p. 91.

> perforated with seven holes like the iron visor of a warrior, thus affording a passage to the images of visible things.[1]

According to Quekett, Viviani in his Life of Galileo stated that Galileo was led to the discovery of the microscope through that of the telescope, and in 1612 he sent one to Sigismund, King of Poland. Viviani also stated that Galileo worked twenty years at his apparatus in order to perfect it.[2]

Galileo's discovery was unique and apparently separate from the activity in Holland. His instrument was responsible for the origin of the name microscope. "The name Microscope, like that of telescope, originated with the Academy of the Lincei, and it was Giovanni Faber who invented it, as is shown by his letter to Prince Federigo Cesi, President of the Academy of the Lincei, written April 13, 1625. 'I only wish to say this more to your Excellency . . . concerning the new inventions of Signor Galileo . . . do as you think best. As I also mention his new occhiale to look at small things and call it microscope as the Linceum gave to the first the name of telescope so they have wished to give a convenient name to this also; and rightly so. . . .'"[3]

The Simple Microscope

Throughout the period from the advent of the microscope in the seventeenth century to the nineteenth century, there was a steady

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[1]Charles Singer, "The Dawn of Microscopical Discovery," Journal of the Royal Microscopical Society, n. v. (August, 1915), p. 328, quoting John Wodderborn, Quatuor problematum quae Martinus Horky Contra Nuntium Sidereum de quatuor planetis novis dioputanda proposuit confutation (Padua: n. p., 1610), [no page number given by Singer].

[2]Quekett, p. 3.

[3]Disney, p. 98.

development of the simple microscope. Some of the well-known ones should be mentioned because the simple microscopes were used frequently by students in the classroom. The simple microscope was preferred to the compound microscope by many microscopists until the achromatic microscope was developed. With a simple microscope an enlarged, erect image of an object may be seen. The simple microscope always consists of one or more converging lenses or lens-systems, and the object must be placed within the principal focus.[1]

Galileo's microscope might be considered to be a simple microscope although Govi claimed that Galileo should receive recognition for inventing the compound microscope.[2] However, Disney stated that Galileo's instrument was not a true compound microscope as the purpose of the eye-lens of a true compound microscope is to magnify the image rather than to parallelize the rays as was the function of Galileo's microscope.[3]

In 1637, Descartes in his writing, Dioptrique, illustrated a simple microscope with biconvex lens. Interestingly this device was reinvented by both Leeuwenhoek and Lieberkuhn according to Clay and Court.[4]

The "flea microscope" which was popularly used for about a century was apparently first introduced around the middle of the

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[1]Gage, pp. 1 & 2.

[2]G. Govi, "The Compound Microscope invented by Galileo," Journal of the Royal Microscopical Society, Trans. unknown n.v. (1889), p. 575.

[3]Disney, pp. 1 & 2.

[4]Clay and Court, p. 14.

seventeenth century. Athanaseus Kircher (1602-1680) in his book Ars Magna Lucis et Umbrae of 1646, stated that he had been given a microscope by John Carolus Cardinal Medices which consisted of a tiny glass sphere mounted at one end of a short tube.[1] This type of microscope became known as the flea microscope.

From 1673 to 1723, Anthony Leeuwenhoek (1632-1723), did much of his work and became well-known as one of the early microscopists. Leeuwenhoek gave little information about his microscopes except to say that they were single.[2] After Leeuwenhoek's death, his microscopes which he had given to the Royal Society were examined by Henry Baker who reported that the lens on the tiny microscopes which were held up next to the eye were double-convex and ranged in power from one-fifth to one-twentieth of an inch and magnified from forty to 160 diameters. Baker examined only twenty-six of Leeweuwenhoek's microscopes even though he had constructed many more. In fact, in the collection examined by Baker "every Microscope herein was engaged by an Object affixed to it, and thereby rendered useless for any other purpose. . . . Many of them too must certainly have been much greater magnification than any in our Possession."[3]

An interesting single microscope, the water microscope, was described by Stephen Gray in 1696. When a globule of water in which

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[1]Clay and Court, p. 32, quoting Athanaseus Kircher, Ars Magna Lucis et Umbrae (n.p., 1646), p. 835.

[2]Ibid., pp. 33 & 34.

[3]Henry Baker, "An Account of Mr. Leeuwenhoek's Microscopes," Philosophical Transactions. Giving Some Account of the Present Undertaking, Studies, and Labours of the Ingenious in Many Considerable Parts of the World, XLI (September, October, November, 1740), pp. 507-508. [Hereafter referred to as Philosophical Transactions.]

there were particles more opaque than the water was placed near his eye, he could see those particles distinctly and highly magnified.[1] In another description of his microscope, Gray stated that his microscope frame consisted of five pieces of brass and was about one-sixteenth of an inch thick. A spherical cavity in which the water was placed was about one-eighth inch diameter and half the thickness of the brass frame. A double convex lens of water was formed; this made the objects more distinct.[2]

At the turn of the seventeenth century, the screw barrel microscope was developed and stayed essentially in its original form for at least a hundred years.[3] According to Clay and Court, the screw barrel microscope was first described by N. Hartsoeker (1656-1725) in his book, Dioptrique, in 1694.[4] In part because James Wilson (c. 1665-1730) described the screw barrel microscope to the Royal Society in 1702, he is usually given the credit for inventing it.[5] Essentially the screw barrel microscope consisted of one tube inside another, and it was focused by screwing the tube in or out. A set of eight different glasses with different magnifying powers was included with Wilson's

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[1]Stephen Gray, "Several Microscopical Observations and Experiments," Philosophical Transactions, XIX (June, July, August, 1696), p. 281.

[2]Stephen Gray, "A Letter from Mr. Stephen Gray, giving a further Account of his Water Microscope," Philosophical Transactions, XIX (November & December, 1696), p. 354.

[3]Clay and Court, p. 42.

[4]Ibid.

[5]Ibid.

microscope.[1] Pocket microscopes mentioned so often in nineteenth century popular works in microscopy were screw barrel microscopes.[2]

The next major development in the simple microscope was the appearance of the Lieberkuhn microscope in 1740. Jean N. Lieberkuhn (1711-1756) used a concave speculum to illuminate opaque objects. As was noted above, this was first suggested by Descartes, used by Leeuwenhoek, but popularized by Lieberkuhn.[3]

One of the last important simple microscopes to be developed was the aquatic microscope which was produced by John Cuff (1703-1772) in 1750. This model microscope is mentioned often by those doing biological work, and "aquatic microscopes" are frequently mentioned as classroom equipment. It was a pocket microscope built so the lens could be moved in order to bring it over any point of the stage that was desired. From then on any microscope in which objectives were mounted on an arm giving them such a movement were called "aquatic" microscopes.[4]

The Compound Microscope

The compound microscope is one which gives an enlarged inverted image and consists of two optical parts, (1) an objective which produces an enlarged, inverted real image of the object and (2) an ocular acting

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[1]James Wilson, "The Description and manner of Using a late Invented Set of small Pocket Microscopes, made by James Wilson, which with great ease are apply'd in viewing Opake, Transparent and Liquid Objects: as the Farina of the Flowers of Plants, &c. The Circulation of the Blood in Living Cretures, &c. The Animalcula in Semine, &c.," Philosophical Transactions, XXIII (September & October, 1702), pp. 1242-43.

[2]Clay and Court, p. 52.

[3]Ibid., p. 64.

[4]Ibid., pp. 66 & 67.

in general like a simple microscope to magnify this real image.[1] The microscope popularized by Drebbel which was supposedly invented by the Jansens was then, indeed, a compound microscope according to Peiresc's description.[2]

The properties of compound objectives and compound oculars were pointed out by Johann Kepler (1571-1636) in 1611 in the Dioptrice.[3] René Descartes (1596-1650) in the Dioptrique in 1637, described a compound microscope. Clay and Court believed this is the earliest known drawing of a compound microscope, but they doubted it was constructed.[4]

One of the greatest of the early microscopists was Robert Hooke (1638-1703) whose Micrographia was first published in 1665. In this book there appeared a detailed and illustrated account of his compound microscope which was the first published detailed account according to Clay and Court.[5] They also believed that in all probability Hooke's microscope dated back to 1660.[6] This microscope was modeled on the

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[1]Gage, p. 11.

[2]Humbert, p. 155.

[3]Disney, p. 71. "If a hollow lens be set up and two like convex lenses be applied very close together, instead of one alone, they almost halve the length of an instrument which has only one of those convexes; at the same time they reduce the magnitude of the image." Proposition CXXV. "If two concave lenses almost in contact be further distant from a convex lens than one only of them would be, so that they give distant vision, then they must increase the image of the visible object and almost double it." Proposition CXXVII.

[4]Clay and Court, p. 14.

[5]Reginald S. Clay and T. H. Court, "Some Developments of the Hooke Microscope" Journal of the Royal Microscopical Society, n. v. (December, 1924), p. 357.

[6]Clay and Court, History of the Microscope, p. 28.

telescope of that period in respect to the number of draw tubes, the cup-shaped eye-end, and the method of supporting the instrument with a ball and socket joint which was frequently used in the seventeenth century.[1]

Hooke described his microscope as follows:

> The Microscope, which for the most part I made use of, was shap'd much like that in the sixth Figure of the first Scheme, the Tube being for the most part not above six or seven inches long, though, by reason it had four Drawers, it could very much be lengthened, as occasion required; this was contriv'd with three Glasses; a small Object Glass at A, a thinner Eye Glass about B, and a very deep one about C: this I made use of only when I had occasion to see much of an Object at once; the middle Glass conveying a very great company of radiating pencils, which would go another way, and throwing them upon the deep Eye Glass. But when ever I had occasion to examine the small parts of a Body more accurately, I took out the middle Glass, and only made use of one Eye Glass with the Object Glass, for always the fewer the Refractions are, the most bright and clear the Object appears.[2]

Hooke also stated that he made a microscope by using a tube of brass with a convex object glass at either end and put water in between the two glasses. He stated that this was quite inconvenient, and thus he never did use it.[3]

It was thought for a long time that the field lens which was included on Hooke's microscope was introduced by him. Clay and Court found that Balthasar de Monconys (1611-1665) gave a description of his

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[1]Clay and Court, "Some Developments of the Hooke Microscope," p. 358.

[2]Robert Hooke, Micrographia: or Some Physiological Descriptions of Minute Bodies made by Magnifying glasses with Observations and Inquiries thereupon. (London: The Council of the Royal Society of London for Improving of Natural Knowledge, 1665), p. [f. verso].

[3]Ibid., [f_2 recto].

microscope which included a field lens in his book, Voyages, which was published in 1665.[1]

Clay and Court also found among some manuscripts of the Sloan Collection a copy of a letter written by Dr. Henry Power (? - 1668) to Richard Reeves (n.d.) in August, 1662. From the contents of this letter, it could be ascertained that Reeves was fitting all of his microscopes with a field lens before 1662.[2]

An important development for the compound microscope was the addition of a focusing screw which allowed the operator to focus the microscope easily with one finger. According to Clay and Court, Johannis Hevelius (1611-1687) was the first to use the focusing screw as there is a figure drawn of it in his book. He had made this addition to one of Hooke's microscopes because as his book was written in 1673, the addition of the focusing screw was made sometime prior to that date.[3]

The next major improvements in the compound microscope were made by John Marshall (c. 1663-1725) at the end of the seventeenth century. In Harris' Lexicon Technicum published in 1704, there is a fold out page illustrating "John Marshall's New Invented Double Microscope,

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[1]Clay and Court, History of the Microscope, p. 21 citing Baltharsar de Monconys, Journal des Voyages de Monsieur de Monconys (Lyon, France: H. Boissart & G. Remers, 1665-66), p. 128.

[2]Reginald S. Clay and Thomas H. Court, "Note on the Introduction of the Field Lens in the Microscope; Dr. Henry Power and His Letters," Journal of the Royal Microscopical Society, LIV (1934), pp. 23-28.

[3]Clay and Court, "Some Developments of the Hooke Microscope," pp. 361-62 citing Johannis Hevelius, Machina Coelestis (n. p., 1673), p. 303.

for viewing the Circulation of Blood."[1] John Harris (1677-1719) also described Marshall's microscope. Some of the important advances were: the use of the strong rigid arm which carried the body and which was inclinable; the stage is on the same arm as the pillar so that "the axis of the Microscope is always kept perpendicular to that point of the Object, over which it was first placed . . . .";[2] Hevelius' fine adjustment screw is included as well as a well-graduated set of objectives. The author concluded by stating: "I have had Mellens's Glasses, and seen Levenhoeck's and Compani's, but I would sooner have the Double Microscope than any of them, and the Price is much easier."[3]

Another popular microscope was the microscope which was invented by Edward Culpeper (1600- c. 1740) between 1725 and 1730. In addition to being convenient to use and comparatively easy to manufacture, Culpeper's microscope included the concave illuminating mirror. For this reason it was called the "Double Reflecting Microscope." Although Culpeper either went out of business or died around 1740, his microscope was widely copied.[4]

The next well-known microscope to appear was the "Universal" microscope which was made by George Adams (1708-1773). It was described and illustrated in his Micrographia Illustrata which was first published in 1746. The improved design demonstrated by this microscope was the

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[1]John Harris, Lexicon Technicum: or, an Universal English Dictionary of Arts and Sciences; Explaining not only the Terms of Art, but the Arts Themselves (London: Printed for Dan. Brown, et al., 1704), p. [5 I 2 recto].

[2]Ibid., p. [5 I 2 verso]. [3]Ibid.

[4]Clay and Court, History of the Microscope, p. 108-09.

mounting of the microscope on a much improved and more rigid folding tripod. In addition, it had six objectives of different strengths which were mounted on a revolving circle.[1]

Although there were many new designs of microscopes, the more advanced and important ones have been reviewed. Each improvement represented an important step in the evolution of the microscope as an important tool for the scientist. Many were actually the microscopes that were used in the science classroom during the nineteenth century while many others used in the classrooms were improved copies of those microscopes that have been reviewed above. Improvements to the design of compound microscopes were continually made throughout the nineteenth century.

The Achromatic Microscope

In spite of the many advances made in the development of the compound microscope, they were on the whole very unsatisfactory because of chromatic aberration. This is due to the fact that "ordinary light consists of waves of varying length, and as the effect of a lens is to change the direction of the waves, it changes the direction of the short waves more markedly than the long waves. Therefore, the short waved, blue light will cross the axis sooner than the long waved, red light,

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[1] George Adams, Micrographia Illustrata or The Knowledge of the Microscope Explain'd: Together with an Account of a New Invented Universal, Single or Double Microscope, Either of which is capable of being applied to an Improv'd Solar Apparatus (London: Printed for and sold by the author, 1746), pp. 1-2.

and there will result a superposition of colored images, none of which are perfectly distinct."[1]

The development of the achromatic microscope is relatively unknown. Its "invention" is credited to several different men at various times. Generally the incorporation of achromatic lens occurred after the 1820's.

According to Hogg, as late as 1821, Edward Constant Biot (1803-1850) wrote "opticians regarded as impossible the construction of a good achromatic microscope."[2] In 1828, William Hyde Wollaston (1766-1828?) wrote:

> With respect to the apparatus for magnifying, notwithstanding the great improvements likely made in the construction of the microscope, by the introduction of achromatic object-glasses, and the manifest superiority they possess over any single microscope, in the greater extent of field they present to view at once, whereby they are admirably adapted to made an entertaining exhibition of known objects, hardly anyone of the compound microscopes which I have yet seen, is capable of exhibiting minute bodies with the extreme distinctness which is to be attained by more simple means, and which is absolutely necessary for an original examination of unknown objects.[3]

The above two remarks are cited to show that although achromatic lenses had been introduced and were well-known by the third decade of the nineteenth century, they were still not completely accepted or utilized. This fact most probably had a great influence on the acceptance of the microscope into the classroom as a tool in teaching science.

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[1]Gage, p. 4.

[2]Jebez Hogg, The Microscope: Its History, Construction, and Application Being a Familiar Introduction to the Use of the Instrument and the Study of Microscopical Science (6th ed. London: George Routledge & Sons, 1867), p. 7.

[3]William Hyde Wollaston, "A Description of a Microscopic Doublet," Philosophical Transactions of the Royal Society of London, CXIXX (1829), p. 9.

Achromatic lenses were first developed for use in telescopes. Chester Moor Hall (1703-1771) made achromatic objectives for his telescope in 1729, and according to Frison he made them regularly from the year 1733, although he never patented them.[1] John Dolland (1706-1761), a practical optician, apparently learned of the invention from George Bass, who ground the lenses for Hall's achromatic combination.[2] John Dolland read a paper before the Royal Society on June 8, 1758, describing how the achromatic lenses were made:

> To make therefore two spherical glasses, that shall refract the light in contrary directions, it is easy to understand, that one must be concave, and the other convex; and as the rays are to converge to a real focus, the excess of refraction must evidently be in the convex; and as the convex is to refract most, it appears from experiment, that it must be made with crown glass, and the concave with white flint glass.[3]

For this work, Dolland received the Copley medal of the Royal Society.[4]

Sobol contended that Leonard Euler (1707-1783) first advanced the idea of creating an achromatic objective in 1747, by using a combination of glass and water. Sobol believed Dolland got his ideas from Euler.[5]

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[1]Ed. Frison, L'Evolution de la Partie Optique du Microscope au Cours du Dix-Neuvième Siècle les test Objects, les test-Probe-et-typen-Platten. Communication No. 89 du Rijksmuseum voor de Geschiedenis der Natuurwetenschappen (Leyden: Museé National d'Histoire des Sciences Exactes et Naturelles, 1954), p. 24.

[2]Charles Singer, et al. (eds.), A History of Technology, Vol. IV: The Industrial Revolution 1750 to 1850 (New York: Oxford University Press, 1958). p. 358.

[3]John Dolland, "An Account of Some Experiments concerning the Different Refragibility of Light," Philosophical Transactions, L (1758), p. 741.

[4]Frison, p. 24.

[5]S. L. Sobol, "On the History of the Invention of the Achromatic Microscope," Actes du VIII^{e} Congrès International d'Histoire des Sciences, II (September, 1956), p. 800.

A third version of the invention of achromatic lenses was presented by Nordenskiöld. He stated that Samuel Klingenstierna (1698-1765), a professor of physics at Upsala, succeeded in working out how achromatic glass should be made, and under his instructions Dolland constructed the first achromatic lens.[1] Singer stated that Klingensterna published the mathematical theory of the achromatic objective in 1765.[2]

In 1827, Fresnel expressed surprise that the opticians had neglected the application of achromatic lenses to microscopes since they had been employed for a long time in telescopes.[3] Frison explained that because it was so difficult to make achromatic lenses of very small dimensions, the application of these lenses to microscopes had been retarded.[4]

In 1771, Louis-Francois Dellebarre (1726-1805) invented a microscope which was acclaimed by some as being an achromatic microscope.[5] Dellebarre's microscope was based on the theories of Euler

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[1]Eric Nordenskiöld, The History of Biology: A Survey. trans. Leonard Bucknall Eyre (New York: Tudor Publishing Co., 1928), p. 389.

[2]Singer, History of Technology, p. 358.

[3]M. Fresnel, "Rapport sur les Microscopes de M. Selligue," Annales de Chimie et de Physique, XXVII (1824), p. 43.

[4]Frison, p. 23.

[5]J. F. Montucla, Histoire des Mathématiques Dans laquelle on rend compte de leurs progrès depuis leur origine jusqu'a nos jours; où l'on expose le tableau et le développement, des principales decouvertes dans toutes les parties de Mathématiques les contestation qui se sont elevées entre les Mathématiciens, et les principaux traits de la vie des plus célèbres (Tome Troisieme, Paris: Chez Henri Agasse, 1802), p. 511.

which were published in the Memoires de l'Academy of Petersburg in 1766 and 1767. Montucla stated that Dellebarre's microscope was one of the best of that time.[1]

Montucla stated that the men of the Academy of Science had studied Dellebarre's microscope and Montigny, le Roy, and Brisson made their report on June 21, 1777.[2] There is a note that a microscope by Dellebarre had been approved by the Academy and would be added to their collection in the 1777 issue of the Academy's Histoire.[3]

Frison explained that Dellebarre had attempted to obtain achromation of his oculars by means of incorporating the lenses of crown and flint alternately. Some of his microscopes had up to six lenses that were superimposed within the ocular. According to Frison, it is absolutely impossible to achromatize by simply superimposing the biconvex crown and flint lenses.[4] Therefore, Dellebarre's microscope probably cannot be considered a true achromatic microscope, but it should be noted as an historical attempt to construct an achromatic microscope.

Frison stated that Benjamin Martin (1704-1782) made achromatic triple objectives for his Opaque Solar Microscope. Martin described this in a pamphlet which has been dated by Frison as appearing around 1774. Frison also noted that "an excellent drawing of this type of

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[1]Ibid., p. 515. [2]Ibid., p. 511.

[3]Histoire de l'Académie Royale Des Sciences Année MDCCLXXVII Avec les Mémoires de Mathématique et de Physique pour la même Année, Tirés des Registror de cette Académie (Paris: L'Imprimerie Royale, 1780), p. 69.

[4]Frison, p. 25.

microscope with his perfected objective is found in the work 'Het Mikroskopp gemakkelijk' de Henry Baker, traduction néerlandaise de Martinus Houttuyn, Amsterdam, 1778."[1] This is seemingly one of the earliest references to the actual construction of an achromatic microscope.

Sobol claimed that the opticians of the Academy of Sciences, Kulibin (n. d.) and Belynev (n. d.), made the "first achromatic microscope in history."[2] Euler's pupil, Nicholau von Fuss (1755-1826), made calculations under Euler's direction for an achromatic microscope. Construction was begun in December, 1772, when grinding forms were manufactured; by September, 1773, the manufacture of the flint glass optics was completed; and by April, 1775, Kulibin reported to the Academy of Sciences that the work on this complex "new type" microscope, which had proceeded under Euler's guidance, had been completed.[3] As Sobol admits, nothing is known of the fate of this microscope. He doubts that the opticians could grind the necessary thin lenses at that period; the microscope was probably a failure.[4]

Epinus (n. d.) described before the Conference of the Academy of Sciences in St. Petersburg on April 8, 1784, a new achromatic microscope which he had invented. He converted the achromatic telescope into a microscope by extending the tube. In 1784, he built a microscope which was four feet long, which used a telescopic objective (f = 17.5 cm), and which had a magnifying power of sixty to seventy diameters.[5] According

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[1]Frison, p. 24.

[2]Sobol, p. 800.

[3]Ibid., p. 801.

[4]Ibid.

[5]Ibid., p. 802.

to Sobol, George Adams made some very disparaging remarks about this microscope in his famous book on microscopes which was published in 1787, and nothing more was ever said about Epinus' achromatic microscope.[1]

However, according to Frison in his study of the development of achromatic microscopes, the objective of the acrhomatic microscope is generally attributed to Francois Bieldonyder (1755-1808). Around 1791, Bieldonyder made a triple combination of two crown biconvex lenses with one biconcave lens between them. This microscope is in the collections of the University of Utrecht and has been studied in detail.[2]

Around 1807, Harmonus van Deijl (1738-1809) commercially produced achromatic microscopes. Five of his achromatic instruments still exist; two are at the University of Utrecht, one is at the Teyler Museum at Haarlem, and two are at the Risksmuseum voor de Geschiedenis der Natuurweterschappen in Leyden.[3]

The achromatic objectives were composed of one flint biconcave lens and one crown biconvex lens; the flint surface was turned towards the object. As Frison pointed out, Van Deijl had realized more than seventeen years before Charles Chevalier (1804-1859) the correct positioning of the lenses to reduce their spherical aberration.[4]

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[1] Ibid.

[2] Frison, p. 26. [Frison never mentions any of Epinus' work, and the edition of George Adams' work of which Sobol writes was not available for study. Sobol is the only one to mention his work.]

[3] Ibid., pp. 26-27.

[4] Ibid.

An achromatic microscope which dates from 1808 was found in the old laboratories of the Academy of Sciences in Leningrad in 1939. The plans for this microscope were found in Epinus' papers after his death in 1802. Christopher Fredrich Parrot (1751-1812), a pupil of Epinus, had two of these microscopes made by Tideman in Stuttgart.[1]

During the 1820's, there was increased activity among microscope makers to improve the achromatic microscope. In 1823, experiments were begun in France by Selligue, by Frauenhofer in Munich, by Amici in Modena, by Chevalier in Paris, and by Goring and Tulley in London.[2] Selligue's microscope was presented to the Academie des Sciences on April 5, 1824. According to Hogg, this microscope was constructed by Chevalier for Selligue.[3] Selligue's achromatic lens was composed of a crown and a flint lens. To obtain more magnification, he used up to four of these achromatic lenses for the objective. His instrument's magnification was a maximum of fifty and a minimum of twenty-five or thirty diameters.[4]

Also in 1824, Charles Tulley (? - 1830) in England, without knowledge of Selligue's work, constructed an achromatic object-glass for a compound microscope under the direction of C. R. Goring (1792-1840).[5] Tulley used a triple lens.

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[1]Sobol, p. 802.

[2]Hogg, p. 7.

[3]Ibid., p. 9.

[4]Fresnel, pp. 47-48.

[5]Hogg, p. 9.

In 1825, Charles Chevalier (1803-1859) made another achromatic microscope. This one was far superior to the one he made the year before for Selligue.[1]

Giambattista Amici (1786-1863) had been engaged as early as 1815, in working with achromatic object glasses, but he had quit work on them and began work on a reflecting microscope. After Selligue's work was announced in 1824, he began working on the achromatic microscope again. In 1827, he took some excellent ones to England.[2] One was a horizontal microscope in which the object-glass was composed of three superimposed lens with a big aperture.[3]

The work of Joseph Jackson Lister (1786-1869) proved to be the beginning of a period of splendor for the English optical science according to Frison.[4] Lister's work was, of course, based on that done before him. His work was influenced in particular by Amici's findings.[5] The improvement he effected was to join a plano-concave flint lens and a convex lens by means of a transparent cement, Canada balsam. This cut down the loss of light during reflection; the clearness of the field and the brightness of the picture was increased by doing this. He also discovered the two aplanatic foci of a combination.[6]

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[1]Joseph Jackson Lister, "On Some Properties in Achromatic Object-Glasses Application to the Improvement of the Microscope." Philosophical Transactions of the Royal Society of London, CXX (1830), p. 188.

[2]Ibid., p. 189. [3]Hogg, p. 9. [4]Frison, p. 34.

[5]William B. Carpenter, The Microscope and its Revelations, Enlarged, edited, and revised by W. H. Dallinger (7th ed. London: J. and A. Churchill, 1891), p. 305.

[6]Lister, pp. 194-195.

After Lister's work appeared, achromatic microscopes were manufactured on a greater scale than ever before. They became available for use in the laboratories of investigators and in the classrooms. Important advances and improvements were made and have been made continually since that period, but the stage was set at that particular time for the utilization of the microscope in a more productive fashion than had been possible up to that time.

Summary

In order to understand the availability of the microscope and the types of microscopes available to the nineteenth century educators, the evolution of the microscopes has been reviewed. It has been noted that although men of the ancient Grecian period and the Middle Ages were familiar with the phenomenon of magnification, it was not until around the beginning of the seventeenth century that the first microscopes appeared. During a thirty-year period, 1590 and 1620, microscopes were probably invented independently by both Galileo in Italy and the Jansens of Holland.

The development of the single microscope and the compound microscope throughout the ensuing centuries was also reviewed. Special reference has been made to those microscopes which were used in the science classes during the nineteenth century.

Because the development of the achromatic microscope was so vital to the serious use of the microscope, it has also been reviewed. Achromatic lenses which were first developed for the telescope in the early eighteenth century, were experimentally used in microscopes in the late eighteenth and very early nineteenth centuries and were finally

perfected enough so that mass production and use were possible by the fourth decade of the nineteenth century. Improvements were continually made to the achromatic microscope throughout the nineteenth century which further enhanced it as a tool for the teaching of the sciences.

The appearance of the microscope in the science classroom depended greatly on the evolution of the microscope as a cheap, readily available, and relatively uncomplicated tool with which to work. Only after establishing this background of the evolution of the microscope as such a tool could the actual adoption of the microscope as an instrument in teaching science be fully explored. The availability of microscopes during the nineteenth century will be reviewed next as this also furnishes a background for the general use of the microscope in American universities and colleges.

CHAPTER III

AVAILABILITY OF MICROSCOPES IN THE NINETEENTH CENTURY

Before microscopes could be utilized widely to teach science during the nineteenth century, moderately-priced microscopes of uniform type had to be available. Microscopes were constructed and sold during the seventeenth and eighteenth centuries by lens makers, but the number of people and firms involved in the production of microscopes seemed to increase during the nineteenth century after the development of the achromatic microscope. Perhaps this was true because it was possible after that time to use the microscope as a tool for serious research. Although many firms were concerned with the production of the microscope, only some of the ones whose founding dates were found in the literature are listed below.

The Continent

One of the first makers of improved achromatic microscopes, Charles Chevalier, founded the firm of Chevalier and Sons in Paris sometime after 1825. In 1845, another firm founded by Nachet began producing microscopes in France also.[1]

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[1]Frank F. Münez with Harry A. Charipper, The Microscope and Its Use (New York: Tudor Publishing Co., 1943), p. 14.

Two firms, Pistor and Schieck, were both manufacturing achromatic microscopes in Germany by 1834. The Viennese firm, Ploessl who supplied microscopes throughout the nineteenth century, also began production around 1834.[1] The firm which makes the famous Leitz microscopes was founded in 1865, when Edward Leitz purchased the Kellner optical works.[2]

According to Hughes, the continental instruments were favored for their quality even by the British scientists. "We are told that Bowman found French microscopes considerably cheaper for class use than were those of the English firms."[3]

England

Several famous English firms were formed shortly after the most effective improvements were made to the achromatic microscope. Ross began manufacturing achromatic objectives applying Lister's principles soon after Lister's paper was given in 1830.[4] Lister's nephew, Beck, and a Mr. Smith formed a partnership known as the R. & J. Beck Co. in the early 1830's.[5] In 1832, the renowned firm of Powell and Leland was established.[6]

Around the middle of the nineteenth century, English, as well as French, German, and even American, manufacturers were advertising

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[1]Arthur Hughes, A History of Cytology (London and New York: Abelard-Schuman, 1959), p. 10.

[2]Mūnez, p. 19. [3]Hughes, p. 10.

[4]Jabez Hogg, The Microscope: Its History, Construction, and Application Being a Familiar Introduction to the Use of the Instrument and the Study of Microscopical Science (6th ed. London: George Routledge & Sons, 1867), p. 10.

[5]Mūnez, p. 14. [6]Ibid.

microscopes which were especially designed for students. According to Smallwood, Carpenter in The Microscope and Its Revelations devoted no less than sixteen pages to the various designs of both student and educational microscopes that were available at that time in England.[1]

Beale described a student microscope brought out by Salmon in 1853. He stated this was the first manufacturer to bring out really good, practical instruments furnished with good object-glasses which sold at very low prices. This particular microscope cost five pounds.[2]

Beck, in his book on achromatic microscopes published in 1865, described the "Educational Microscope" made by that company; a detailed technical description and instructions for use of the microscope were included.[3] Not all of Beck's instruments were student microscopes; the microscope used by Charles Edwin Bessey at the Iowa State College in 1871, which had been purchased from Beck cost twelve hundred dollars.[4] By 1877, the Iowa State College was supplying a compound microscope to each student enrolled in Physiological and Cryptological Botany. These were Beck's "Economic Microscopes" which cost thirty-five dollars each.[5]

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[1]William Martin Smallwood with Mabel Sarah Coon Smallwood, Natural History and the American Mind (New York: Columbia University Press, 1941), p. 205.

[2]Lionel S. Beale, How to Work with the Microscope (London: Harrison, Pall Mall, 1880), p. 13.

[3]Richard Beck, A Treatise on the Construction, Proper Use, and Capabilities of Smith, Beck, and Beck's Achromatic Microscopes (London: John van Voorst, Paternoster Row, 1865), p. 80.

[4]Ernst A. Bessey, "The Teaching of Botany Sixty-Five Years Ago," Iowa State Journal of Science, IX (January, 1935), 216.

[5]Ibid., p. 233.

United States

Microscopes were available from American manufacturers by the middle of the nineteenth century. Charles A. Spencer (1813-1887) is thought to have been the first to make microscopes commercially in the United States.[1] It is said that Spencer visited J. W. Bailey at West Point in 1847, and saw a Chevalier microscope which had been made for a Dr. Gillman. Spencer said he had made a better one, and Dr. Gillman ordered one of Spencer's microscopes which was delivered in the fall of 1847.[2] Spencer continued to make microscopes throughout the years, and in 1877, the official firm of Charles A. Spencer and Sons was founded.[3] Evidently, the quality of these microscopes was quite high for when F. A. P. Barnard, the president of Columbia College, submitted some of Spencer's objectives in the Paris Exposition in 1878, they were awarded the gold medal for superiority.[4]

Edward Bausch, whose father was one of the founders of the Bausch and Lomb Optical Company, made his first microscope in 1872, and exhibited one at the Philadelphia Centennial in 1876. According to Mūnez, Bausch was the first man to organize the production of microscopes in quantity in America.[5] Both scientists and teachers directly influenced the development of microscopes and the microscope industry in the United States as is illustrated by a statement written by Edward Bausch:

> My wedding trip in 1878 took me to Boston which was the best market for our microscopes. We did not know why we were selling more

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[1]Mūnez, p. 14-15. [2]Ibid.

[3]Smallwood, p. 207. [4]Ibid.

[5]Mūnez, p. 19.

> Microscopes in that locality than in the other larger cities, but I called upon the firm acting as our agents, and learned from them that Dr. Oliver Wendall Holmes was recommending to his students that they buy their Microscopes from this young firm in America and support this new industry. That recommendation of Dr. Holmes' was of tremendous aid to us. He examined each microscope before it was accepted by the students.[1]

Mention of student microscopes began in the 1850's in the United States. In 1857, J. & W. Grunow & Co. of New Haven, Connecticut advertised their microscopes in the American Journal of Education. Also a review of the J. & W. Grunow & Co. catalog, "Illustrated Scientific and Descriptive Catalogue of Achromatic Microscopes," appeared in The American Journal of Science. Five of the eight microscopes described in the catalog were either student or educational microscopes.[2] Particular attention was called to the educational microscopes in the advertisement:

> They call the particular attention of Students and Teachers to their Educational and Students' Microscopes which are provided with object-glasses sufficient for all ordinary investigations, and of a quality never before sold by any American or foreign maker at prices so low.[3]

In 1868, a description of a new student microscope made by Joseph Zentmeyer appeared in The American Naturalist. It was also noted that due to an increasing importance of inexpensive and portable microscopes and an increasing demand for good instruments which were especially

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[1]Smallwood, p. 207 quoting from a MS address by Edward Bausch at Meeting of The Optical Society of America, at the Brooklea Country Club, Rochester, New York, May 5, 1931. MS in possession of Smallwood.

[2]"Miscellaneous Intelligence," The American Journal of Science and Arts, ser. 2, XXIV (1857), 448.

[3]J. & W. Grunow & Co., The American Journal of Education, IV (1857), 847.

adapted to work in histology and pathology, the prominent microscope makers were led to introduce so-called student microscopes of excellent quality and remarkable economy.[1]

Just how important and extensive the practice of manufacturing student microscopes was at that time is noted in an article written by Ward in 1872, about available student microscopes in the United States. He described twenty microscopes made by ten different companies.[2] The microscopes ranged in price from fifty to one hundred dollars. Ward stated that this price included a walnut or mahogany case, and the price varied with the quantity and quality of work and the reputation of the maker. The feeling seemed to be that any microscope which cost less was unsatisfactory and one which cost more was unnecessary.[3] Ward also stated that the American objectives were unreasonably expensive; otherwise they compared favorably with the English ones.[4]

In 1877, Bessey described a simple microscope which he required each student to buy for the botany course in Structure and Classification. It was a simple, brass three-legged microscope with a magnifying power of nine diameters; it cost seventy-five cents.[5] Bessey did not provide information about who manufactured this little microscope.

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[1] "Microscope," The American Naturalist, I (1868), 379.

[2] R. H. Ward, "Students' Microscopes," The American Naturalist, VI (June, 1872), 326-29.

[3] Ibid., p. 325.

[4] Ibid., p. 322.

[5] Bessey, p. 233. From a letter written by Charles E. Bessey dated December 31, 1877, to Dr. W. J. Beal at Michigan Agricultural College.

Summary

It can be seen that microscopes were available in Europe particularly after the improvement of the achromatic instrument after 1830, throughout the rest of the nineteenth century. Microscopes were also being manufactured after 1850, in the United States. It seems that companies in Germany, France, England, and the United States developed and advertised economically cheap, quality microscopes which were sold as student microscopes after the middle of the century.

It has also been pointed out that at least ten companies were producing twenty models of student microscopes in the early 1870's in the United States. Although these were more expensive than comparative microscopes from England, there seemed to have been a demand for them. These high quality compound microscopes were selling from between fifty and one hundred dollars. It was also noted that simple microscopes which had a magnification of nine diameters were available for seventy-five cents each.

It can be concluded that a supply of good and relatively inexpensive microscopes was being produced for student use and was available after 1850, both in the United States and in Europe.

CHAPTER IV

THE MICROSCOPE IN FOREIGN UNIVERSITIES

In studying the advent and use of the microscope in the teaching of science in American higher education, it is necessary to review first this development in the European universities. As the United States was struggling to establish itself during the nineteenth century, it was only natural that many educational philosophies and activities were influenced by those of the European universities. In order to understand what was happening in the American colleges and universities it is necessary to study the general pattern of development in the use of the microscope in universities of Europe.

Before the microscope could be utilized to teach science either as a method of demonstration or use by students in the laboratory, it was necessary for an empirical approach to be adapted by the universities in the teaching of courses relating to natural philosophy and science. According to Irsay, this shift to the empirical method of teaching was occurring as early as the seventeenth and eighteenth centuries in the northern European countries. The University of Leyden was among the first to utilize this method; astronomy was taught by observation during the seventeenth century. The teaching of botany included well-organized practical work. A medical clinic for practicing and also

teaching of medicine was established in 1636 at this University.[1] The University of Edinburgh was oriented toward the natural sciences in a rationalistic spirit as was the University of Leyden; they exhibited a parallel evolution of the empirical teaching of natural sciences.[2] Although this method of teaching science was not adopted by all European universities the impetus for the early utilization of available scientific tools was established and was influential.

Germany

Germany, in particular, exhibited a tendency toward the teaching of scientific subjects by empirical methods probably for several reasons. By the end of the eighteenth century, there had been established throughout Germany a strong intellectual tradition which was predisposed to welcome a great development of public education under the supervision of the state. This strong, intellectual tradition was founded on the principle of freedom of thought which was necessary for the assimilation and teaching of science.[3] The strong state control of education which developed affected the total educational system.[4]

A close relationship between the development of the sciences and of the universities had been established. Those men who were the

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[1]Stephen d'Irsay, Histoire des universités francaises et étrangères des origines à now jours. Tome II: Du XVI^{e} siècle à 1860 (Paris: Auguste Picard, 1935), pp. 14-15.

[2]Ibid., p. 23.

[3]M. E. Sadler, "The History of Education," Germany in the Nineteenth Century, ed. J. H. Rose et al. (3rd ed.; Manchester: University Press, 1915), p. 108.

[4]Ibid., p. 120.

great scientists were also the teachers in the institutions of higher education.[1] In part due to the view that higher education should be composed of specialized instruction and advanced courses for original work, the view that scientific research was the main purpose of the university was impressed upon Germany.[2] Sadler, in discussing the relationship between education and science in Germany during the nineteenth century quoted Merz:

> "The German man of science was a teacher. He had to communicate his ideas to younger minds, to make the principles and methods of research clear . . . to draw out original talent in others, to encourage co-operation in research, to portion out the common work to the talents which surrounded him."[3]

Sadler explained:

> These characteristics rose in great measure from the educational conditions under which German science sprang up. The educational system of the country affected the methods of scientific research; scientific research in its turn quickly affected the educational system. There was nothing comparable to this in England. The reorganization of German education began from the top with the reform of the Universities.[4]

Other authors also stressed the relationship of scientific research and education in Germany during the nineteenth century. Paulsen stated that the German university laboratory was utilized both for scientific research and for instruction. The university was the important seat of scientific research. Thus the student was introduced both to scientific knowledge and to research as the universities began

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[1]Rudi Berthold et al., Die Humboldt - Universitat Gestern - Heute - Morgen (Berlin: Veb Deutscher Verlag der Wissenschaften, 1960), p. 73.

[2]Sadler, pp. 109-110. [3]Ibid., p. 120.

[4]Ibid.

with the assumption that truth must be discovered.[1] The university teacher was an original investigator, and he encouraged his pupils to participate in his labors and therefore trained them to continue his work. Thus, the universities, not the academies of science, became the centers of scientific work in Germany in the nineteenth century.[2]

Scientific research was introduced to students in a variety of ways. From the beginning of the nineteenth century, the demonstration method of instruction began with anatomy, was extended to practical medical courses, and then continued on to the natural sciences and physiology. As the chief concern of the teacher, who was also an investigator in the branch of science he taught, was to convey the results of his research, he showed and explained to the students his finished preparations.[3]

Also during the first half of the nineteenth century, the practice of allowing students to participate in research was begun in the small private laboratories of the teacher.[4] This led to the development of student laboratories. The first instructions in the use of the microscope and its actual use by students probably began within these small private laboratories.

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[1]Friedrich Paulsen, The German Universities and University Study, trans. Frank Thilly and William W. Elwand (New York: Charles Scribners Sons, 1906), pp. 5-6.

[2]Ibid., p. 161.

[3]Theodor Billroth, The Medical Sciences in the German Universities: A study in the History of Civilization, trans. with an introduction by William H. Welch (New York: The Macmillan Company, 1924), p. 37.

[4]Paulsen, p. 218.

Another circumstance which probably led to student use of the microscope in Germany earlier than in other countries was the subject matter of scientific investigation. Early in the nineteenth century, the German investigators turned to morphological research. Embryology, cytology, etc., received much emphasis.[1] These courses encouraged the use of the microscope. As soon as the achromatic microscope had been developed, the way was open for morphological research. Since the educational system provided an opportunity for student participation, student use of the microscope was possible early in the nineteenth century in Germany.

According to Frison, Hugo von Mokl stated that at the commencement of the nineteenth century there were in Germany many universities where one had trouble finding a single microscope suited for use, and it was even more difficult to discover a man who could use it correctly.[2] This situation seemingly began to be altered after the development of reliable achromatic microscopes and the beginning of cellular and morphological research.

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[1]Paul Livingstone Hollister, "Development of the Teaching of Introductory Biology in American Colleges" (unpublished Ph.D. dissertation, George Peabody College for Teachers, August, 1939), p. 80.

[2]Ed. Frison, L'Evolution de la Partie Optique du Microscope au Cours du Dix. Neuvième Siècle les test Objects, les test-Probe-et-typen-Platten. Communication No. 89 du Eijksmuseum voor de Geschiednis der Natuurwetershappen (Leyden: Musée National d'Histoire des Sciences Exactes et Naturelles, 1954), p. 124 citing M. Mobius, Geschichte der Botanik von der ersten anfängen bis zur Gegenwart (Jena: Fischer, 1937), p. 436.

The University of Heidelburg

An example of the early use of the microscope by a student in a professor's private laboratory is furnished by several incidents which had occurred in Louis Agassiz's (1807-1873) school life. He and several of his friends including Alexander Braun (1805-1877) who became a renowned botanist, were very good friends with the botany professor Bischoff (n.d.) when they attended the University of Heidelburg in 1826. "They [Agissiz and his friends] owed to him [Bischoff] a thorough and skillful instruction in the use of the microscope, handled by him like a Master."[1]

The following year, 1827, Agassiz and Braun transferred to the University of München. Here he lived in the home of Ignaz Döllinger (1770-1841). Agassiz, in writing his autobiography, stated: "With Döllinger I learned to value accuracy of observation. As I was living in his house, he gave me personal instruction in the use of the microscope, and showed me his own method of embryological investigation."[2]

An incident which occurred much later in the nineteenth century illustrated how the student use of a microscope by means of private instruction from a friendly professor in Agassiz's day had evolved into class utilization of the microscope. Around 1872, Nicolaus Jacob Carl Müller (1843?-1901), a professor of botany at the University of Heidelburg, sent a notice concerning his utilization of the microscope in his

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[1]Elizabeth Cary Agassiz (ed.), Louis Agassiz: His Life and Correspondence (London: Macmillan and Company, 1885), I, 29-30. This information was furnished by Alexander Braun to Mrs. Agassiz after Agassiz's death.

[2]Ibid., I, 150.

botanical lectures to the Botanische Zeitung. This notice was translated and published in The American Naturalist for the benefit of others "who desire the help of the microscope in illustrating scientific lectures."[1]

> The objections to the plan of bringing in a number of instruments under each of which a preparation has been placed, are many and serious. The most important is perhaps the difficulty which one unaccustomed to the use of the microscope has in understanding the new and strange appearances presented, and that while looking at the prominent objects in sight, such as air bubbles and foreign bodies of marked and strong outline, he misses altogether the real object which ought to have been seen. The experiment of using the ordinary microscope as a solar microscope and presenting the image of the object on a screen where it could be seen by the whole class at once, and their attention directed to the important points, was tried last summer, and with the most marked success. He used one of Hartnack's first class instruments clamped in a horizontal position and received the image on a screen distant from five to eight metres making an image of two to three metres in diameter. An heliostat and one or two condensing lenses directed the light on the object. The microscope was so placed that the stage was somewhat this side of the focus of the collecting lens. When images were desired as free as possible from spherical aberration the ocular was removed and the image taken directly from the objective; when on the other hand the greatest possible amplification was desired, then both objective and ocular were used. In this way by the use of Hartnack's immersion lenses the finest test objects were exhibited, and the six sided spaces of the Pleurosigma shown as four to five millimeters in diameter.[2]

The University of Breslau

Another illustration of early student use of the microscope was at the University of Breslau in the early part of the nineteenth century. This was a progressive school for that time; the first independent anatomy teaching laboratory was established there in 1814, and then a physiology laboratory was established there by Johannes Purkinje (1787-1869)

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[1] T. D. B. "The Microscope in the Lecture Room," The American Naturalist, VI (1872), 314.

[2] Ibid., pp. 314-315.

in 1824.[1] Purkinje was not only a great scientist and the first microscopist of his time, according to one biographer, Stŭdnicka, but also as a teacher who utilized knowledge ahead of his age.[2] According to another biographer he was appointed to Breslau over the opposition of the faculty.[3] He soon caused trouble by asking for a microscope; the authorities could not understand why a physiologist needed a microscope.

> If this were permitted to go on, the university would be cluttered up with apparatus and specimens, and the students would be occupied in performing experiments instead of reading. . . . Evidently the arguments failed to convince Purkinje, for in an unoccupied corner of the college building he opened the first physiological laboratory.[4]

By 1830, Purkinje had changed from use of a simple microscope to use of an achromatic microscope in order to study ciliary movement.[5] According to Stŭdnicka, "he was interested in experiments and demonstrations [when teaching students], but above all in the latter with the help of a microscope."[6] Once he had an achromatic microscope, he invented a

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[1]Abraham Flexner, Medical Education in Europe, A Report to the Carnegie Foundation for the Advancement of Teaching. Bulletin Number 6, New York City, 1912 (Boston: [Printed by The Merrymount Press, 1912]), p. 3.

[2]F. K. Stŭdnicka, "Jan Evangelista Purkyne [Purkinye] [1787-1869], Osiris II (1936), 473-481.

[3]Victor Robinson, "Johannes Evangelista Purkinje," The Scientific Monthly, XXIX (1929), 221. [Purkinje was a Czech which may have made him unwelcome by the faculty.]

[4]Ibid.

[5]Arthur Hughes, A History of Cytology (London and New York: Abelard-Schuman, 1959), p. 9.

[6]Stŭdnicka, p. 473.

projection microscope so that his students could see his preparations as he lectured.[1]

The University of Berlin

Another outstanding institution instrumental in the educating of scientists was the University of Berlin which was founded in 1809. The University of Berlin helped form a classical natural science in the nineteenth century which evolved into the modern disciplines of the twentieth century. The Academy of Science was also situated in Berlin, and, according to Berthold, the collaboration of these two institutions--many of whose faculty members held joint appointments with the academy--helped to strengthen the development and teaching of natural science.[2]

In 1831, Johannes Müller (1801-1858) was appointed to the Chair of Anatomy,[3] which included anatomy, physiology, embryology, and pathology as late as 1850.[4] It is known that Müller used the microscope in the teaching of his courses, for Russell stated: "Müller gave a new impulse to the study of pathological anatomy by the introduction of the microscope."[5] The exact time he initiated this use and how he implemented its use in the classroom were not described by Russell.

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[1]Gordon Rattray Taylor, The Science of Life, A Picture History of Biology (New York: McGraw-Hill Book Company, Inc., 1963), p. 245.

[2]Berthold et al., p. 70. [The University of Berlin is now known as The Humboldt University, and it is located in the Russian sector of Berlin.]

[3]Eric Nordenskiöld, The History of Biology: A Survey. trans. Leonard Bucknell Eyre (New York: Tudor Publishing Co., 1928), p. 289.

[4]Flexner, p. 8.

[5]James E. Russell, German Higher Schools (New ed.; New York: Longmans, Green and Co., 1916), p. 102.

The practice of students doing work under the personal direction of the professor in his private laboratory was also evident at the University of Berlin in the early years of the institution. Jacob Henle (1809-1885) and Theodore Schwann (1810-1882) were both Müller's students. Hughes and a biographer of Schwann stated it this way:

> The sense of adventure of which these men were conscious is expressed in a remark of Henle's which related to the time in 1834 when he and Schwann were working side by side in Müller's laboratory. "Those were then happy days which the present generation might well envy us, when one saw the appearance of the first good microscopes from the firms of Plessl at Vienna and from Pistor and Schieckat at Berlin, which we students bought with what money we were able to save."[1]

The lack of a plentiful supply of microscopes for student use at the time Schwann and Henle were students was also pointed out by Watermann. He quoted von Morawitz, who stated: "Schwann war besonders wit mikrosckopischen Studien occupiert (1834!) . . . Dieses war das einzige in den Berliner Anatomischen Institute verfugbare Mikrosckop!"[2]

During this period, the emphasis on science oriented courses was increasing at the University of Berlin. In 1820, only twelve percent of the total lectures given were in science and mathematics. By 1830, fifty-three percent of all lectures were given in science and mathematics. Irsay also stated that the equipment in student

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[1]Hughes, p. 10, quoting Q. L. Frédéric, Théodore Schwann, Sa Vie et ses Travaux (Liege: n. p., 1884), p. 13.

[2]Rembert Watermann, Theodor Schwann Leben und Werk (Düsseldorf: L. Schwann, 1960), p. 20 quoting P. von Morawitz "Vor hundert Jahren in Laboratorium Johannes Müllers," Münchener medizinische Wechenechrift, LXXXI (1934), 60-64. Schwann was particularly occupied with microscopic studies (1834!) . . . . This was the only available microscope in the Berlin Anatomical Institute!

laboratories was perfected rapidly, and student work in laboratories was realized early.[1]

Seemingly, the use of microscopes by students in science education and the number of available microscopes did increase at the University of Berlin throughout the years, for during the summer session of 1868, a practical microscopical course was offered. This practical course in microscope technique was taught for two hours each week. The usual techniques were shown and demonstrated on microscopic preparations; therefore, the students had several hours practice per week with ready-made material.[2]

By 1883, a new east wing had been added to the Anatomical Institute, and included in this wing was a very great and broad room for the practical-microscope course. An adjoining room was also assigned for the teaching of the practical-microscope course.[3] Seemingly an increasing emphasis was being placed on the role of the microscope in science education.

Other German Universities and Schools

By the 1870's microscopical studies and microscopical work by students was fairly widespread throughout the German universities. Many students went to particular universities in order to study in a well-known scientist's laboratory. During this period, many American students

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[1] Irsay, II, 282.

[2] Max Lenz, Geschicte der koniglichen Friedrich-Wilhelms-Universitat zu Berlin, Dritter Band: Wissenschaftliche anstalten Spruchkollegium. Statistik (Halle: Buchlandlung des Waisenhauses, 1910), p. 134.

[3] Ibid., p. 135.

were going to Germany for just this purpose. Flexner related that William Henry Welch (1850-1934) wanted to study histology, but no American medical school offered such a course at that time. Therefore Welch went to the University of Strasbourg and studied normal histology under Waleyer (n.d.) in 1876. "Each student was assigned a microscope; on Mondays the profesor gave 'minute directions how to prepare specimens for the week,' and after that the student was supposed to come into the laboratory whenever he pleased and work on his own with little or no help from above."[1] In August, 1876, Welch went to the University of Leipzig to study microscopical anatomy with Ernest Wagner (1829-1888) at the Pathological Institute. Here he learned methods of preparing and mounting specimens.[2]

During the nineteenth century, nine schools of technology were established in the German empire. They approximated the universities in both instruction and organization.[3] The microscope was evidently used to teach the sciences at these institutions by the 1870's. The American Journal of Education featured in 1870, a series of articles describing the programs in the technical schools of Europe. The use of the microscope is referred to quite frequently which provides the impression that the microscope was a commonly accepted tool by that time.

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[1]Simon Flexner and James Thomas Flexner, William Henry Welch and the Heroic Age of American Medicine (New York: The Viking Press, 1941), p. 79.

[2]Ibid., p. 82.

[3]Paulsen, p. 112.

In the description of the natural philosophy course taught at the Royal Agricultural Academy of Poppelsdorf, Prussia, the following was presented:

> Practical exercise in using the microscope, and experiments as to the physiology of plants: (a) Use of microscope. Introduction to the use of the microscope. Exhibition and preservation of microscopic preparations, and practice in microscopic investigations; (b) Introduction to experiments on plants. The student will have the opportunity of personally testing the most important question in the physiology of plants. For example the examination of transpiration, nourishment, the influence of light, of warmth, etc. Only those students who have heard the necessary preparatory lectures can take part in these microscopic and physiological experiments.[1]

At the Technical University of Württemberg in the Technical Division, the microscope was used one afternoon a week in teaching natural history.[2] Pharmacists, who were enrolled in the chemical school of the Mathematical Division, had chemical and microscopical practice during their first year and microscopic pharmaceutical practice during their second year.[3] Both the Higher Industrial School at Chemnitz, Saxony and the Agricultural Academy in Plagwitz, Saxony utilized the microscope to teach plant physiology.[4]

The microscope was seemingly absent in the teacher training schools of Germany. An American professor at the Duluth Normal School in the United States, who had visited in Germany after the turn of the

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[1]"Special Instruction in Prussia," The American Journal of Education, XXI (1870), 213.

[2]"Special Instruction in Wurtemberg," The American Journal of Education, XXI (1870), 367.

[3]Ibid., p. 369.

[4]"Special Instruction in Saxony," The American Journal of Education, XXI (1870), 301 & 313.

century, reported: "In visiting normal schools in Germany last year, I found that they were not equipped with microscopes. Their biology was nature study training."[1]

Great Britain

In England quite a different educational system and philosophy of education existed than in Germany; hence the method and manner of teaching science and the consequent role of the microscope were also quite different. However, the increasing use of the microscope in the teaching of science is evident throughout the nineteenth century.

In comparing English education with German education, the one great difference which is most evident and which probably had the greatest effect on the teaching of science in the universities was the lack of control by the state. In England, the power of the state was used reluctantly; there was an apparent deliberate rejection of any comprehensive plan of national reorganization throughout the nineteenth century. While Germany adopted the principle that national education was a function of the state, England hesitated between two opposing theories, the theory of private initiative and the theory of state control. This ended with complicated machinery but with no well-defined system of national education.[2]

Sadler divided English education into three phases: (1) 1800-1840, which was characterized by a deepening of spiritual life at Oxford

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[1]B. L. Seawell, "A Symposium on the Teaching of Biology and Nature Study in Normal Schools," School Science and Mathematics, VIII (May, 1908), 371-372.

[2]Sadler, p. 114.

and Cambridge; (2) 1840-1870, which was characterized by an effort to modernize and to develop university studies; and (3) 1870-1900, which was characterized by the first effort of the state to provide compulsory education for children and the foundation of new universities and great developments in the old ones.[1]

English education differed from German education in that a strong social tradition existed in England in contrast to a stronger and more widely diffused intellectual tradition in Germany.[2] Consequently, the scientists of the nineteenth century in England on a whole were separate from the university professors. Scientific life and university life were two different spheres. The various scientific societies, such as The Royal Society were the scientific centers during the nineteenth century. The greatest progress in microscopic science was made by the many groups of amateurs which existed in England.[3] The Royal Microscopical Society was one example of these groups.

The two ancient universities, Oxford and Cambridge, stubbornly resisted the encroachment of the sciences upon their curricula.[4] Haines quoted Lyell who commented:

> After the year 1839, we may consider three-fourths of the sciences, still nominally taught at Oxford, tho [sic] have been virtually

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[1] Ibid., p. 116.

[2] Ibid., p. 119.

[3] Maria Rooseboom, "The Introduction of Mounting Media in Microscopy and Their Importance for Biological Science," Actes du VIIIe Congrès International d'Histoire des Sciences, n.v. (Paris: Hermann & Cie Dépositaire Général, 1958), p. 603.

[4] George Haines IV, German Influence upon English Education and Science, 1800-1866 (Connecticut College Monograph, No. 6; New London, Connecticut: Connecticut College, 1957), p. xii.

> exiled from the University. . . . Chemistry and Botany attracted between the years 1840-1844, from three to seven students; Geometry, Astronomy and Experimental Philosophy scarcely none.[1]

During the eighteenth and early nineteenth centuries, science courses were taught mainly by the dissenting academies in England. These were educational institutions of university standing which were established for those who could not attend Oxford or Cambridge because of their religious affiliations.[2] As the universities' curricula tended to be more classical, the academies were attuned to science, modern languages, and more common subjects. The dissenters put into practice the theories of Commenius' English followers such as Hartlib, Milton, and Petty.[3]

Haines stated that laboratory teaching and handwork seemed proper only for craftsmen.[4] Perhaps this attachment of prestige to classical training was another reason why the universities were slow to accept the responsibility of teaching science courses with the concomitant laboratory method. The first mass teaching of science by the laboratory method was conducted by a special department of the government and not by the universities. In 1850, the Government School of Mines and Science came into existence, and in 1852, the Department of Practical Arts was established and by 1853, a Science Department was added. The Science and Art Department was responsible for administering parliamentary

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[1] Ibid., p. 14.

[2] Irene Parker, Dissenting Academies in England (Cambridge: University Press, 1914), pp. 50-57.

[3] Ibid., pp. 135-137.

[4] Haines, p. 58.

grants which were to encourage the teaching of science and the arts throughout the country. These subsidies were known as South Kensington grants, and, at first, these courses were taught primarily in evening classes. In 1851, thirty-eight science classes were attended by 1300 pupils; by 1861, there were seventy science classes with 2,543 students.[1] In these courses, the laboratory teaching of science with the microscope as an essential tool was introduced into the whole of English education by Thomas H. Huxley as will be discussed below.

The Scottish Universities

Between 1750 and 1840, the Scottish universities and the men educated in these universities were responsible for transmitting scientific knowledges of the Dutch, French, and Germans.[2] Many of the Scottish educators received additional education in the continental schools; their learnings were then passed on to the English who were attending the Scottish universities.[3] As early as 1759, at the University of Edinburgh there was a recognition of the need for instruments as well as for books in order to carry on experimental knowledge in areas such as mechanics, optics, practical astronomy, among others.[4] The University of Glasgow owned apparatus for experimental philosophy such as an eight foot telescope and a prism as early as 1693. By 1704, a botanic garden, a botany teacher, and apparatus to teach botany had been procured.

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[1]H. C. Barnard, A Short History of English Education (London: University of London Press, 1952), pp. 157-158.

[2]Haines, p. 1. [3]Ibid.

[4]Christopher Wordsworth, Scholae Academicae: Studies at the English Universities in the Eighteenth Century (Cambridge: University Press, 1910), p. 178.

Between the years 1714 and 1744, instruments valued at over £300 had been acquired by the University of Glasgow.[1]

After 1840, as German leadership in the sciences became apparent, the German influence on English science became direct.[2] The influence of Scottish universities as leaders of science education for Great Britain declined as is reflected by the apparent slowness of the English to adopt laboratory teaching of modern biological courses. In spite of the early brilliant utilization of tools by Scottish universities to teach natural philosophy, there is very little in the literature and histories to indicate the continuation of this method of education. Grant in the history of the University of Edinburgh indicated that one of the graduates of that University, John Hughes Bennett (1812-1875), went to Europe following his matriculation. There, according to Grant, he acquired expertise in the use of the microscope. Returning to Edinburgh in 1841, he began giving extramural courses of lectures in histology which he continued for some years.[3] How Bennett utilized the microscope in his classes is not described by Grant. The lack of information concerning practical work in the modern biological sciences within the Scottish universities indicates that probably they were quite slow in teaching modern biological courses and in adapting

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[1]James Coutts, A History of the University of Glasgow, from its Foundation in 1451 to 1909 (Glasgow: James Maclehose and Sons, 1909), p. 195.

[2]Haines, p. 1.

[3]Alexander Grant, The Story of the University of Edinburgh During Its First Three Hundred Years (London: Longmans, Green, and Co., 1884), II, 410.

the laboratory method of teaching with utilization of the microscope.

One of the few references to the use of the microscope in Scottish universities was cited by Bower. A practical class in botany was organized by Balfour (n.d.) at the University of Glasgow in 1879. As the professor was responsible for the whole financial conduct of his department, the professor had to buy all of the students' microscopes and other apparatus.[1]

Oxford University

Although disinterest in scientific subjects has been noted during the nineteenth century in the English universities, Oxford maintained an extensive collection of microscopes which dates from the eighteenth century. Gunther, who has done considerable research in the teaching of science at Oxford, listed fifteen microscopes which were produced in the eighteenth century. Also in the collection is a set of seven ivory slides with microscopic objects in place which dates from 1702 and which is the earliest set of microscopic preparations according to Gunther. Among the microscopes were two Wilson screw barrel microscopes dating from 1702, a "Double Microscope for viewing the Circulation of Blood" made by John Marshall in 1693, a Culpeper microscope, a "Cuff's Double Constructed Microscope and Stand" made by Dolland in London in 1761, and a "Cuff's Double Constructed Microscope and Stand

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[1]F. O. Bower, Sixty Years of Botany in Britain (1875-1935) Impressions of an Eye-Witness (London: Macmillan and Co., Limited, 1938), pp. 38-39.

with an oblique Mirror for Solar Illumination" made by George Adams between 1746 and 1741.[1]

Gunther explained that there was an appreciation of the beauty and interest of scientific instruments in the seventeenth centuries. Also by the beginning of the eighteenth century, natural philosophy was being taught by the college lecturers.[2] During the first quarter of the eighteenth century, demonstrations in experimental philosophy were given by J. Whiteside (n.d.) who was Keeper of the Ashmolean Museum which contained the valuable collection of apparatus.[3] It seems probable that at this time the microscope, itself, was being studied as a natural or scientific phenomenon, and therefore it was not used as a tool to learn more about a particular field of science such as zoology or botany.

One of the earliest uses of microscopes to help in the teaching of a biological course at Oxford was made by Henry Wentworth Acland (1815-1900) who used microscopes in illustrating his histology lectures which began October 22, 1845, in the Lecture Theatre at Christ Church.[4] According to Sinclair and Robb-Smith, Acland came under the influence of Richard Owen (1804-1892) who was the Hunterian Professor of Comparative Anatomy and Physiology in the early 1840's. Owen introduced

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[1]R. T. Gunther, Early Science in Oxford. Vol. I: Chemistry, Mathematics, Physics and Surveying (Oxford: Reproduced Photographically at the University Press, 1942 [First printed for the Subscribers in 1923]), p. 120.

[2]Ibid., pp. 195-196. [3]Ibid., p. 199.

[4]R. T. Gunther, Early Science in Oxford, Vol. III: The Biological Sciences and The Biological Collections (Oxford: [Printed for the Subscribers, 1925]), p. 120.

Acland to the use of the microscope and its importance in anatomical studies.[1]

One of Acland's students who was present at the first histological lecture was William Tuckwell (1829-1919) who later wrote a description of the course. The uniqueness of both the subject matter and also the method of teaching is demonstrated in the following quotation:

> In 1844 Dr. Acland, settling in Oxford as a physician on Dr. Wootten's early and lamented death, was made Lee's Reader of Anatomy at Christchurch. The subject had not formed part of University studies; Sir Christopher Pegge had drawn small audiences to fluent desultory lectures; Dr. Kidd, who vacated the chair to Dr. Acland, had published a monograph on the anatomy of the mole-cricket, whose novelty moved the mirth of his professional brethern. The small theatre contained a cast of Eclipse's skeleton with a few dreary preparations in wax; corpses were sent from the gallows for dissections, at which an intending medical student would now and then assist; there was a tradition that the body of a woman hanged for murder had once, when laid out on the table, shown signs of life, had been restored by the professor, and dismissed, let us hope to sin no more. In Oxford, or out of it, Invertebrate Zoology was a subject little studied, and, while microscopes were costly and imperfect, could not be generally carried out. A comparative anatomist, however, Dr. Acland determined to be. Going to Shetland for practical work amongst the marine fauna, he encountered Edward Forbes, employed on the same errand; shared his labours, caught his enthusiasm, and profited by his knowledge. Appointed to the Christchurch Chair, he amassed slides and preparations, introducing the first microscope which had been seen in Oxford. He employed for dissection the deft fingers of J. G. Wood, then an undergraduate; from the yet more skillful hands of Charles Robertson - who, under his tuition, became afterwards Aldrichian Demonstrator and tutor for the Science Schools, and whose "Zoological Series" gained a medal in the Exhibition of 1861 - proceded nearly all the beautiful biological preparations now on the Museum shelves. The lectures began in 1845; they were delivered in the downstairs theatre, whence we ascended to the room above, to sit at tables furnished with

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[1]H. M. Sinclair and A. H. T. Robb-Smith, A Short History of Anatomical Teaching in Oxford (Oxford: University Press, 1950), p. 49.

> little railroads on which ran microscopes charged with illustrations of the lecture, alternately with trays of coffee. A few senior men came from time to time, but could not force their minds into the new groove. Dr. Ogle, applying his eye to the microscope, screwed a quarter-inch right through the object; and Dr. Kidd, after examining some delicate morphological preparation, while his young colleague explained its meaning, made answer first, that he did not believe in it, and secondly, that if it were true he did not think God meant us to know it. So we were mostly undergraduates; and greatly we enjoyed lectures, microscopes, and the discussions which Dr. Acland encouraged; though these last exercises were after a time suppressed, as endangering lapses into the leve et lucicrum.[1]

Sinclair and Robb-Smith also stated that the trustees decided that the demonstrations were not lectures and hence should not be given.[2] Neither Tuckwell nor Sinclair indicated when the demonstrations stopped.

The use of microscopes had not been curtailed completely for a very long period of time because it is known that Lionel Smith Beale (1828-1906) used them in teaching many of his courses. Beale received his early training from Acland who spurred his interest in microscopy.[3] During 1852, Beale established a laboratory of his own in which he taught microscopy and physiology.[4] He became professor of physiology and anatomy at King's College in 1853. Beale stated that he exhibited and described at each of his lectures at King's College three or four specimens; he used microscopes with low powers which were well adapted for every kind of class demonstration.[5] Beale's book, How to Work with

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[1]W. Tuckwell, Reminiscences of Oxford (London: Cassell and Company, Limited, 1900), pp. 44-46.

[2]Sinclair and Robb-Smith, p. 53.

[3]Ibid.

[4]G. H. Brown (ed.), "Lionel Smith Beale," Lives of the Fellows of the Royal College of Physicians of London 1826-1925 (London: Royal College of Physicians of London, 1955), p. 100.

[5]Lionel S. Beale, How to Work with the Microscope (London: Harrison, Pall Mall, 1880), p. 5.

the Microscope, was first written in 1857 and was based on a course of lectures given during the 1856-57 school year in order to help students surmount an elementary detail of microscopical work and more mechanical operations.[1]

In the 1880 edition of this book, Beale described a cheap student microscope made by a Mr. Salmon in 1853. He stated that this was the first really good, practical instrument made especially for students. It had good object-glasses and only cost 5.[2]

In another place he described a simple microscope which functioned as a clinical, pocket, travelling, and class microscope which he had used for class demonstrations for years. It not only was inexpensive,but it was also constructed simply. Beale stated that he was able to show more than twelve preparations magnified from fifteen to 500 diameters to a class of nearly 100 during an hour's lecture with this type of microscope.[3]

George Rolleston (1829-1881) taught a course at Oxford in comparative anatomy probably beginning around 1860. According to Ray Lankester (1847-1929), Rolleston was the first scientist in England to conduct systematically the study of Zoology and comparative anatomy by making use of a series of animals.

> "He had a series of dissections of these mounted, also loose dissections and elaborate MS. descriptions. The student went through the series, dissecting fresh specimens for himself.

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[1] Ibid., p. vii.

[2] Ibid., p. 13.

[3] Ibid., pp. 17-19.

> After some ten years' experience, Rolleston printed his MS. directions and notes as a book, called Forms of Animal Life."[1]

Rolleston's book was published in 1870. In this book he recommended that microscopic specimens be available for comparison with descriptions and figures given in the textbook.[2] Lankester stated, though, that Huxley gave more attention to microscopic forms and to microscopic structures than did Rolleston.[3] However, the preceding information indicates that Rolleston probably used the microscope occasionally for the purposes of teaching zoology and comparative anatomy at Oxford probably after 1860.

The University of London

The University of London was founded in 1827. Because of a prevailing interest in science and also because of utilitarian influence, the scientific subjects were accepted as important subjects from the time of its foundation. Both pure and applied sciences were taught.[4] The microscope was probably considered an essential tool in the teaching of science at this institution because William Sharpey (1802-1880) instituted a course in practical histology in 1856. "A Lectureship of Practical Physiology was established in 1856, 'with the view of supplying the

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[1]Leonard Huxley, Life and Letters of Thomas Henry Huxley (London: Macmillan and Co., Limited, 1900), I, 377-378, n. 1, quoting from a letter by Professor (Ray) Lankester written to Thomas Huxley.

[2]George Rolleston, Forms of Animal Life Being Outlines of Zoological Classification Based Upon Anatomical Investigation (Oxford: Clarendon Press, 1870), p. vii.

[3]Huxley, I, 377-378, n. 1, citing Lankester.

[4]Haines, pp. 14-16.

Medical Students with instruction in the use of the Microscope in examining textures and fluids of the body.'"[1]

At first the course was taught only during the summer, but by 1859, it was also taught in the winter. Separate rooms were provided for both practical histology and practical physiology (pathology). Bellot stated these courses consisted of distributing sections prepared by the professors for microscopic viewing.[2]

It seems strange that the microscope was utilized for one course at such an early date and seemingly completely neglected in other areas. Sydney Howard Vines (1849-1934) who had received a B.Sc. from the University of London in 1874, where botany was in the schedule of courses had never seen a microscopical section of any part of a plant.[3]

Cambridge University

Microscopes may have been incorporated somewhat into the teaching of science at Cambridge. An inventory of all the microscopes owned by Cambridge University which date prior to 1900 lists twenty-one zoological microscopes and nine botanical microscopes. The majority of these microscopes date after 1850. There is one aquatic microscope which dates from 1764 and which belonged to Erasmus Darwin; it was listed among the botanical microscopes. Charles Darwin's large microscope which dates from 1847 and his notes on how to use it is included

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[1]H. Hale Bellot, University College London 1826-1926 (London: University of London Press, Ltd., 1929), p. 313, quoting from Annual Report, 1855, 8; 1856, 7, 9.

[2]Ibid.

[3]Bower, p. 49.

in the collection.[1] How these microscopes were used is always the interesting question.

Michael Foster (1836-1907), who had taught practical physiology and histology in 1867, at the University College of London, was appointed Praelector at Trinity in 1870. He was provided a laboratory for use in teaching physiology, elementary biology, and embryology. In 1876, Foster and his demonstrator, J. N. Langley (1852-1925), wrote a textbook, A Course in Practical Physiology and Histology.[2] Bower stated that Foster had a full corps of willing demonstrators. The daily laboratory class which followed the lecture formed a coherent whole. Here a new area of microscopic technique was opened.[3]

In contrast to the vigorous teaching of physiology, Bower stated that the teaching of botany was dead until 1875, when influence of the German botanical research began to be felt in the teaching of botany in Britain. During the summer of 1877, Vines studied at Würzburg under Julius von Sachs (1842-1897) and attended his lectures and laboratory sessions.[4] In 1877, Vines instituted the first practical classes in botany taught at Cambridge; he even provided the microscopes for the students.[5]

Huxley's Course

The year 1872, marked the beginning of an era in the teaching of biology. Thomas H. Huxley's (1825-1895) Department of Natural

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[1] R. T. Gunther, Early Science in Cambridge (Oxford: [Printed for the author at the University Press, 1937]), pp. 365-367; 399-401.

[2] Ibid., pp. 322-323.

[3] Bower, p. 13.

[4] Ibid., p. 23.

[5] Ibid., p. 51.

History in the School of Mines was moved to South Kensington, and "for the first time (except for a trial center with a vacation course the previous summer), he was able to supplement effectively the didactic teaching of the lecture room with well organized instruction in an adequately equipped laboratory."[1]

The summer course had been taught during June and July, 1871; a series of thirty-six lectures was given to school teachers on "teaching science the right way."[2] In a letter dated July 7, 1871, Huxley stated he was using microscopes in teaching schoolmasters principles of biology, but he complained that the English microscopes were not worth the money they cost.[3] These lectures were held in the South Kensington Museum, London. There was no proper laboratory, but the professor and demonstrators rigged up things as they wanted them. The students studied a number of plants and animals; microscopic work was included.[4]

As was stated above, Huxley began teaching with an adequate laboratory in 1872. Huxley believed the laboratory was a necessity in science teaching. On June 4, 1872, he wrote Tyndall about his new course, calling it "the commencement of a new system of teaching which, if I mistake not, will grow into a big thing and bear great fruit, and just at the present moment (nobody is necessary very long) I am the necessary man to carry it out."[5] In further explaining the necessity of laboratory teaching and also illustrating the utilization of the

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[1]Raymond Pearl, "Human Biology in Schools and Colleges," School and Society, XLII (July 27, 1935), 111.

[2]Huxley, I, 357.

[3]Ibid., p. 362.

[4]Ibid., p. 387.

[5]Pearl, p. 111.

microscope in his teaching, Huxley stated the following in his essay, "On the Study of Biology," which was given in 1876:

> My class have, of course, their textbooks, but the essential part of the whole teaching, and that which I regard as really the most important part of it, is a laboratory for practical work, which is simply a room with all the appliances needed for ordinary dissection. We have tables properly arranged in regard to light, microscopes, and dissecting instruments, and we work through the structure of a certain number of animals and plants.[1]

Medical Colleges

The use of the microscope was also introduced into the medical colleges of England during the first half of the nineteenth century. As has been generally true in all other areas, the shift to the use of the microscope as a tool was accompanied with a general switch of emphasis in the whole medical field. Newman stated that the French led the way for the change from clinical medicine to laboratory medicine when they adopted the use of physical signs, i.e., pulse rate, respiratory rate, temperature, etc., to help in their diagnosis.[2] This switch from the patient's psychological symptoms and what the patient told the doctor to the physical signs and structural abnormalities was accompanied by a most remarkable change in medical education which evolved to the detection of structural changes. The switch was not completed until after the turn of the century, and it was awhile before the change

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[1]Thomas H. Huxley, "On the Study of Biology," Science and Education: Essays by Thomas H. Huxley (London: Macmillan and Co., 1893), p. 284.

[2]Charles Newman, The Evolution of Medical Education in the Nineteenth Century (London: Oxford University Press, 1957), p. 265.

could be detected in the curricula.[1] With the change of emphasis to structure, post-mortem findings, and the classification of diseases came the increasing necessity of the use of the microscope and, therefore, the teaching of medical sciences with the microscope.

By 1841, a professorship of histology was established by the Council of the Royal College of Surgeons.[2] By 1845, practical instruction was given in microscopy by a Mr. Birkett at Guy's Hospital which was a medical school in London.[3] Histology and the use of the microscope were taught at University College, the Middlesex, the London, and St. George's as well as Guy's by 1858.[4] "It was not until 1869 that the General Medical Council recommended that microscopy should be included as part of the curriculum."[5]

France

Quite a different picture of science education and of the subsequent role of the microscope is acquired by the investigation of French education. Irsay explained that although science courses were taught at the institutions of higher education in France during the nineteenth century, scientific research had not been combined with the

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[1] Ibid., pp. 82-86.

[2] Hogg, p. vi.

[3] Newman, p. 106. Medical schools were conducted by the various hospitals in England at that time. They were not affiliated with the universities. There were eleven medical schools in London during this period.

[4] Ibid., pp. 108-109.

[5] Ibid., p. 107. General Medical Council Minutes for 1869, 7, London, 1869, p. 86.

universities as in Germany.[1] Nordenskiöld helped to explain why the microscope was not as frequently employed in research in France:

> Whereas in France, then, the experimental method as applied to biology was used for the purpose of finding out purely physical and chemical phenomena in living creatures, in Germany the same method had a somewhat different application; to begin with, it had to serve the purposes of the purely speculative philosophy that was still exercising a dominating influence at the time and was later on practiced in connexion with comparative anatomy, being aided by the use of the microscope. The co-operation had brilliant results; a new direction was given to biology, which placed Germany in the first rank among the center of research in that science.[2]

A Faculty of Sciences was created at the University of Caen in 1809. Evidently the professors were not burdened with instructional work because only one student registered with that faculty in 1830. Bigot stated that no laboratories or instruments were provided for student instruction; the professor used those instruments that he owned personally for teaching.[3]

At the University of Paris, chairs of anatomy and physiology were established in the Faculty of Sciences in 1836. Here, also, according to Irsay, the professor had to equip his own laboratory.[4] Evidently the microscope was used in the teaching of science at the University of Paris in 1853, for the following brief article appeared in The American Journal of Science and Arts:

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[1]Irsay, II, 291.

[2]Nordenskiöld, p. 380.

[3]A. Bigot, "La faculté des sciences," L'université de Caen son passé - son présent, ed. A. Bigot (Caen: Imprimere Artistique Malherbe, 1932), pp. 225-229.

[4]Irsay, II, 292-293.

> The microscopes of Nachet . . . have been employed by Prof. Milne Edwards for a year in his lectures at the Faculty of Sciences of Paris, and the Museum of Natural History. In one of these instruments, made for anatomical demonstrations, two persons may see at once the same object.[1]

The microscope was also being incorporated to teach courses and even special microscopic courses were taught at the University of Paris in 1867. An American doctor who was studying in Paris, Mary Putnam Jacobi (1842-1906), wrote in a letter dated May 12, 1867:

> I have begun to attend a microscope class. . . . This class is extremely enjoyable; there are two physicians, who are both very scientific men, [Ranvier and Carnil] who lecture on alternate days, and who are generally in the laboratory to give instructions and assistance.[2]

In 1868, l'Ecole Practique des Hautes Ètudes was originated. The main objective of the school was to prepare students for the licentiate degree and to give those who had a special scientific aptitute the benefit of the general teaching of the faculty, the special counsels of the best authorized professors of the country, and the means of testing theory by practice at any time or to make personal researches on any scientific question. It was to consist solely of laboratory work. It was composed of four sections: (1) mathematics, (2) natural philosophy and history, (3) natural history and physiology, and (4) historical study and philological science.[3]

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[1]Jerome Nicklès, "Correspondence of M. Jerome Nicklès, dated Paris, Nov. 3, 1854," The American Journal of Science and Arts, ser. 2, XIX (1855), 105-106.

[2]Ruth Putnam (ed.), Life and Letters of Mary Putnam Jacobi, (New York: G. E. Putnam's Sons, 1925), p. 138.

[3]"Special Instruction in France," The American Journal of Education, XXI (1870), 598.

The use and the teaching of the use of the microscope is mentioned extensively in the course descriptions offered at this institute. Microscopic observations and exercises are mentioned as a definite part of the botany program, the laboratory of the faculty of sciences, and the histology course which was held in the laboratory of Milne Edwards.[1]

Summary

The advent of the microscope in the teaching of science in the universities of Germany, Great Britain, and France have been reviewed in order to provide necessary background for the understanding of the use of this instrument in American education. Generally, the microscope was used earlier and more widely by students in Germany than in either Britain or France. As soon as the achromatic microscope became available in the late 1820's, the students in German universities began to use it in the small private laboratories of the professors who were also scientists. After that time the microscope was increasingly utilized throughout the century both to demonstrate at lectures and to be used by students in the student laboratories. The early use of this instrument is credited to several factors: first, a strong state centered and administered educational system made possible the type of research-oriented university which existed in Germany during the nineteenth century; and second, the subject matter of this scientific research which utilized the microscope was prevalent in Germany during the early part of the nineteenth century.

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[1] *Ibid.*

By contrast, England's system of education was characterized by a lack of state organization and direction, and it was also characterized by a strong social rather than intellectual tradition, In general, many of the scientists in England were not university professors. Although the universities owned microscopes which dated back to the eighteenth century, it was not until the fifth decade or so of the nineteenth century that they were used to demonstrate specimens in the science oriented courses. Noticeably lacking in English reference material are topics dealing with student use of microscopes in professor's private laboratories as was the case in Germany. There seemingly was an increasing use of the microscope in the teaching of the sciences after 1840 in England. Although it is generally believed that Thomas H. Huxley introduced first the new concept of laboratory teaching in the 1870's, it had been evolving for quite a few years.

Although France's educational system was an organized scheme of national education, scientific research which had characterized the German universities was not in evidence. The subject matter and the philosophy of science which prevailed in France did not seemingly provide the same impetus for scientific research as in Germany. Although the use of the microscope in teaching courses became evident by the middle of the century in France, there is, as in England, no mention of students working in the professors' private laboratories in the early part of the nineteenth century.

Thus in Europe, it seems that the introduction of the microscope to illustrate scientific lectures and the student use of the microscope depended upon the educational philosophy, the organization of the

educational system, the philosophy of scientific research, and the subject matter of scientific research as well as the availability of the microscope in each individual country.

It seems proper upon reviewing the genesis of the microscope and its use in the classrooms in higher education in Europe that one look to discover whether or not developments similar to those of France, England, or of Germany were apparent in American higher education in the nineteenth century.

CHAPTER V

THE ROLE OF THE MICROSCOPE IN AMERICAN MEDICAL SCHOOLS

After studying the advent of microscopes into European education for purposes of studying biological sciences, it would seem logical to turn to the medical schools of the United States to see the early emergence of the microscope in the teaching of the medical sciences. Therefore, medical education in the nineteenth century will be surveyed in order to discover if the microscope was utilized early in the century to teach the new medical sciences which were emerging after the availability of the achromatic microscopes as happened in the European medical schools.

History of American Medical Education

It is necessary to review the development of medical education in the United States in order to understand both how the medical sciences were taught, and, consequently, how the microscope was used in the teaching of these courses. Medical education did not develop or progress as rapidly in America as it did in the European countries. As Shryock pointed out: "All elements which entered into the development of medical education in this country had already appeared - or at least coexisted in European education. Americans originally borrowed much from

the British, then from the French, and finally from the German institutions."[1]

In reviewing the development of American medical education during the nineteenth century, another distinct difference between the European and the American medical practices should be kept in mind. In Europe, as in the United States, there were many medical practioners who attended either inferior schools or were trained by the apprentice system. However, there was a clear-cut distinction made in Europe between the second-class practitioners and the professional people. This was not so in democratic, nineteenth century America. All practitioners were "doctors" regardless of the amount of quality of training they had received. All were equally recognized.[2] This one fact probably contributed greatly to the slowness of the development of a competent system of medical education.

For purposes of this present study, the development of medical education has been divided into three periods: (1) from 1600 to 1800; (2) from 1800 to 1878; and (3) from 1878 to 1909. The terminal date of the third period is marked by the famed Flexner report which caused a general revising and upgrading of American medical education.[3]

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[1]Richard H. Shryock, "European Background of American Medical Education (1600-1900)," Journal of the American Medical Association, CXCIV (November 15, 1965), 712.

[2]Ibid., p. 711.

[3]Abraham Flexner, Medical Education in the United States and Canada (Report to the Carnegie Foundation for the Advancement of Teaching. Bulletin Number Four. New York City, 1910. Boston: [Printed by the Merrymount Press,] 1912), passim.

1600 to 1800

From 1600 to 1800, on both sides of the Atlantic, apprenticeship played an essential role in the training of medical practitioners.[1] This method of education, called the preceptorial system, was also used for legal and theological education of that period. Over ninety percent of the American physicians were trained in this way before 1800. The student, for a fee of $100, was apprenticed to the physician for a period of at least three years and the apprenticeship lasted until the student was twenty-one. In addition to the preceptors buying the student his basic books the student had free access to the preceptor's library.[2] The student accompanied the physician on all calls and assisted him with the office visits. Toward the end of the period of apprenticeship, the student would be allowed more responsibility in the treatment of patients. Obviously the type of training depended on the preceptor's interest, skill in teaching, and so on. Generally speaking, this system in all probability afforded a better education that that given by the medical schools of the nineteenth century.

A few colleges of medicine came into existence in the United States during the latter part of the eighteenth century however. The College of Philadelphia (which became part of the University of

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[1]Shryock, p. 709.

[2]Frederick Clayton Waite, Western Reserve University Centennial History of the School of Medicine (Cleveland: Western Reserve University Press, 1946), pp. 4-5.

Pennsylvania in 1791) was founded in 1749.[1] The Medical School of King's College, College of Physicians and Surgeons which is now part of Columbia University, was established in 1768.[2] The Harvard Medical School began its long career in 1783.[3]

1800 - 1878

Robinson has called the nineteenth century the "Dark Ages of American Medical Education."[4] In reviewing medical education of this period and in light of the evidence it seems he is probably correct. Three factors shaped and influenced medical education in the nineteenth century: (1) the proprietary school; (2) the two-year ungraded curriculum; and (3) the country medical school. All three factors probably contributed to the apparent backwardness of American medical education.

Flexner[5] and Norwood[6] both cite the foundation of the medical department of the so-called University of Maryland in 1817, as the establishment of the proprietary medical schools. In all, more than

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[1]Francis Randolph Packard, The History of Medicine in the United States. A Collection of Facts and Documents Relating to the History of Medical Science in This Country, From the Earliest English Colonization to the Year 1800. (Philadelphia: J. B. Lippincott Company, 1901), p. 190.

[2]Ibid., p. 218. [3]Ibid., p. 230.

[4]G. Canby Robinson, Adventures in Medical Education: A Personal Narrative of the Great Advance of American Medicine (Cambridge, Massachusetts: Harvard University Press, 1957), p. xi.

[5]Flexner, p. 5.

[6]William Frederick Norwood, "Critical Incidents in the Shaping of Medical Incidents in the Shaping of Medical Education in the U. S." The Journal of the American Medical Association, CXCIV (November 15, 1965), 715.

457 medical schools were established, some on paper only, during the nineteenth century. In 1908, 155 survived.[1]

These proprietary schools were essentially private ventures which were money making in both spirit and objective, and the enterprises were established regardless of the opportunity or the need. All that was essential was to have professors to teach. These professors were local physicians who had practices in the city and who split the students' fees, their only income from the medical school. State boards, as they are now known, did not exist. "The man who had settled his tuition bill was thus practically assured of his degree."[2] Even the medical schools of Harvard, Yale, and Pennsylvania were virtually independent of the institutions with which they were legally united.[3] They were, in fact, proprietary schools operated by the medical doctors in each city.

The ungraded curriculum was introduced shortly after the Revolutionary War. At that time, in part because there was a shortage of medical textbooks and other teaching materials, the faculty of the University of Pennsylvania Medical School temporarily solved the problem by requiring each student to attend two complete courses of lectures--the second being a repetition of the first. This two year ungraded curriculum was quickly copied by other schools.[4] Each "year" course lasted only several months.

This custom was practiced throughout the country until 1859, when N. S. Davis (1817-1904) of the Medical Department of Lind University

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[1]Flexner, p. 6.

[2]Ibid., pp. 6-7.

[3]Ibid., p. 8.

[4]Norwood, p. 717.

(now known as Northwestern University) firmly established a two-year graded curriculum.[1] The graded curriculum was not immediately copied. As late as 1872, the College of Physicians and Surgeons in New York City[2] was described as a two-year ungraded course in which "the work was easy, [there were] no entrance requirements, and nobody failed because the school was supported by student fees."[3] The greatest part of the work was didactic lectures and the student had neither an opportunity to learn pathological histology or to use a microscope.[4]

The third factor which influenced medical education and which was unique to American medical schools was the establishment of country medical schools. These colleges were located in small towns usually free from both any other educational institutions and also from hospitals. During the first half of the nineteenth century, the country medical colleges numbered one-third of all the medical teaching institutions in the United States.[5] Dartmouth which was founded in 1798, was the first country medical school.[6] Most of the faculty were peripatetic

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[1] Ibid.

[2] Simon Flexner considered the College of Physicians and Surgeons the leading medical school in 1872. [Simon Flexner, "William Henry Welch," Science, LII (November 5, 1920), 419.]

[3] Paul F. Clark, Pioneer Microbiologists of America (Madison, Wisconsin: The University of Wisconsin Press, 1961), p. 91.

[4] George Rosen, "Carl Ludwig and His American Students," Bulletin of the Institute of the History of Medicine, IV (October, 1936), 631-632.

[5] Frederick Clayton Waite, The Story of a Country Medical College. A History of the Clinical School of Medicine and the Vermont Medical College Woodstock Vermont 1827-1856 (Montpelier: Vermont Historical Society, 1945), pp. 9-10.

[6] Ibid., p. 15.

professors who taught in more than one institution in the same year.[1] As European ideas of clinical teaching, especially French ideas, were influencing American medical education, the country medical schools started closing in 1840.[2]

By 1870, the general situation was deplorable. As late as that date, at Harvard a student could fail four out of nine subjects, yet he could still get a medical degree and set up practice in Massachusetts.[3] In the early seventies, though, Charles Eliot (1834-1926), the president of Harvard University, began initiating reforms in the medical curriculum. It is interesting to note that these changes were instituted by the university and not by the medical faculty. He extended the medical term from five to nine months, and the period of training from two to three years; he also established a graded curriculum. The medical professors were placed on a salary basis paid by the university. Goddard stated that this upgrading caused Harvard to lose students, but at the same time, it also stimulated a similar upgrading at the University of Pennsylvania six years later.

As the alumni of the University of Pennsylvania were demanding change, the trustees had to force these revisions upon a reluctant medical faculty.[4] For the first time, the University of Pennsylvania medical school professors received their salaries from the University

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[1] Ibid., pp. 24-26.

[2] Ibid., pp. 138-139.

[3] Donald Fleming, William H. Welch and the Rise of Modern Medicine, ed. Oscar Handlin (Boston: Little, Brown and Company, 1954), p. 4.

[4] David R. Goddard, "Medicine and the Universities," Journal of the American Medical Association, CXCIV (November 15, 1965), 724.

instead of from their students. It was announced in the catalogue of 1877-78 that the medical school course would in the future be of three years' length. According to Cheyney, the enrollment increased when the University of Pennsylvania initiated these reforms.[1]

1878 - 1909

During this period of medical education, the laboratory method of teaching the new medical sciences flourished. Charles Sedgwick Minot (1852-1914) of the Harvard Medical School was one of the first to utilize the laboratory method of teaching. Rosen stated:

> He helped immeasureably to establish more correct ideas on medical education. The inclusion and development of histology and embryology as full fledge medical subjects and the teaching of these subjects not only by didactic discourses but to a great extent by practical, objective demonstrations under the microscope certainly tended to raise the standard of medical education in America.[2]

The establishment of the Johns Hopkins Medical School in 1893, represented a big advance in medical education. Based on the German universities medical schools, it embodied the most modern concepts of medical education. The laboratory method was, of course, utilized to teach the latest medical science courses. This was the first school in the United States to demand a Bachelor's degree for admission.[3] By 1902, Harvard University also required an academic degree for admission.[4]

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[1]Edward Potts Cheyney, History of the University of Pennsylvania 1740-1940 (Philadelphia: University of Pennsylvania Press, 1940), p. 275.

[2]Rosen, p. 630.

[3]Abraham Flexner, Medical Education in the United States and Canada, p. 12.

[4]Ibid.

The poor standards which existed generally in the medical schools were brought to light in 1909, when the Flexner report was published.[1] Although the above-mentioned reforms had been initiated, there were many improvements still to be made. As Flexner pointed out, there were too many medical schools and even too many poorly-trained practitioners. In 1909, there was one physician per 568 persons in the United States.[2] Flexner stated these physicians were very poorly trained by the commercial colleges. Of the 155 medical colleges existing in 1909, only sixteen of them required two or more years of college for admittance; fifty of the remainder required a high school education; a highschool education was not even a requirement to be admitted to the other eighty-nine schools.[3]

The commercial medical schools utilized the latest advertising techniques in trying to attract prospective students. False advertising was probably in order also. An item published in 1908, by the Medical Department of the University of Chattanooga is given by Flexner as an example to illustrate both the advertising technique and the paucity of adequate teaching materials: "The department of pathology is provided with a costly collection of specimens and a generous supply of the best microscopes." Flexner stated that only one microscope could be found in the school.[4]

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[1] Ibid., passim.

[2] Ibid., p. 14. Flexner felt the German average of 1 doctor per 2000 persons was a much better ratio.

[3] Ibid., p. 28.

[4] Ibid., fn. 3, p. 19.

Usage of the Microscope

Although there was a slow development of medical education, the microscope was used by medical educators during the nineteenth century before the advent of laboratory teaching. Not much information is available about many of the small proprietary schools, but the example given by Flexner cited above is probably indicative of the equipment of these small commercial schools. The conservativeness of the American medical practitioners probably also delayed the introduction of the use of the microscope into the medical schools. Although philosophical apparatus was procured for some of the medical schools, the microscope was probably not always included. In writing the History of the New England Female Medical College, Waite stated that although teaching equipment was purchased in 1851, it was doubtful that a microscope was purchased because:

> Sanuel Gregory, who contributed one tenth of the subscription fund of $1,000, considered a microscope as "one of those new-fangled European notions." Later he pronounced against "such innovations . . . as thermometers as a proof of incapacity to recognize the ailments of patients." This opinion was held by many medical practitioners when clinical thermometers were first introduced, since they held that any competent physician could recognize a fever in a patient.[1]

Country Medical Schools

In searching the literature, it is found that the earliest uses of the microscope in teaching medicine seems to have been in the country medical schools. The Castleton Medical College was established

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[1]Frederick Clayton Waite, History of the New England Female Medical College, 1848-1874 (Boston: Boston University School of Medicine, 1950), p. 29.

in 1818, and closed in 1862. In 1841, the institution purchased two compound microscopes and used them in demonstrations.[1] A course in microscopical anatomy was taught in 1842. Waite stated: "The demonstrations with the microscope, which began in 1842, were probably confined to normal histology because cellular pathology had not then reached American medical colleges."[2]

Another country medical college, Vermont Medical College which was established in 1827 and closed in 1856, utilized microscopical demonstrations far in advance of many urban medical colleges. Waite quoted from the annual announcements of the school for the years 1847, 1849, and 1855 respectively:

> "The class will be divided into sections for the study of Minute Anatomy and for this purpose the Professor will resort to the aid of the Compound Microscope so that each student may become practically familiar with many of the important facts of Minute Anatomy and Physiology."[3]

> "General Anatomy and Physiology are taught practically . . . . The college is provided with several superior Achromatic Microscopes. These instruments are extensively used, and all the students will be enabled to become familiar with most of the elementary structures and several of the leading physiological phenomena."[4]

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[1]Frederick Clayton Waite, The First Medical College in Vermont Castleton. 1818-1862 (Montpelier, Vermont: Vermont Historical Society, 1949), p. 119.

[2]Ibid., p. 121.

[3]Waite, Story of a Country Medical College, p. 114 quoting Annual Announcement of the Vermont Medical College at Woodstock for the Course of Lectures of 1847 (Woodstock, December 1846), p. 8. [Hereafter referred to as Annual Announcement.]

[4]Ibid., quoting Annual Announcement . . . of 1849 (Woodstock, January 1849), p. 6.

"The Class will be divided into sections for the study of Minute Anatomy, and frequent opportunities will be afforded during the session for the study of the best microscopic preparations of Hett and others; while a microscope belonging to the College will be placed in the dissecting-room, at the disposal of members of the class."[1]

University of Pennsylvania

In examining the advent of the microscope into the first medical college in the United States, it is noted that the use of the microscope was first taught by private tutors and preceptors. Middleton mentioned in the biography of Joseph Leidy (1823-1891) that James McClintock (1809 - ?) was Leidy's private teacher when he began a study of medicine in 1841. When McClintock left Philadelphia to accede to the chair of anatomy in Castleton Medical College in Vermont in 1842, Paul B. Goddard (1811-1866) became Leidy's preceptor. Goddard had given Leidy instruction in the use of the microscope in 1841, at the University of Pennsylvania. As Middleton stated: "In that day a knowledge of the use of the microscope was an unusual accomplishment."[2] In 1848, Leidy went to Europe. On his return, he developed such successful extramural courses in microscopic anatomy and physiology that he was named to the chair of physiology at the University of Pennsylvania. According to Middleton, the honor was never consummated.[3]

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[1] Ibid., quoting Annual Announcement . . . of 1855 (Woodstock, November, 1854 [sic]), p. 6. [Hett was a well known dealer in microscopical preparations in London, England.]

[2] William S. Middleton, "Joseph Leidy, Scientist," Annals of Medical History, V (1923), 102.

[3] Ibid., p. 103.

Another extramural course in the use of the microscope was established by Joseph Janvier Woodward (1833-1884). He had received his Doctor of Medicine Degree in 1853, from the University of Pennsylvania. He then opened an office in Philadelphia and gave private instruction in the use of the microscope and in pathological histology.[1]

In 1866, Dr. James Tysen (1841-1919) was appointed microscopist for the University of Pennsylvania medical school and Blockley Hospital. In the 1867 annual statement for the Guardian of the Poor, there is the following item in the hospital accounts for stock in hand--one microscope valued at two hundred and fifty dollars. Clark stated:

> In the same message, is a report of the microscopist, which after an introductory statement, reads as follows: "As the position was created in 1866, and but few reports [were] called for in the portion of that year during which I held it, these are included in the present summary." There are then listed three microscopic examinations during '66 and four during '67. These are summaries of the detailed descriptions in the Microscopic Register still in the Laboratory. The report concludes "In connection with the additional useful labors recently assumed by the curator of the Hospital, Dr. William Pepper, the position of microscopist should become a useful and important one." Signed, James Tysen.[2]

There is no mention by Clark that students were taught the use of the microscope in pathology classes at this early date. More microscopic examinations were evidently made in the following years, for in 1874, a catalogue containing descriptions of 322 specimens in the pathological

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[1]A. S. Packard, "Memoir of Jeffries Wyman, 1814-1874," National Academy of Science Biolgraphical Memoirs, II (1886), 77.

[2]Jefferson H. Clark, "The Development of a Pathological Laboratory at Blockley," Medical Life, XL (May, 1933), 244.

museum was published.[1] Long stated that Tysen began lecturing on microscopy at the University of Pennsylvania in 1868.[2] If and how the microscope was utilized in the teaching of these classes is not described by Long.

Cheyney stated that it is believed that use of the microscope was taught before 1870:

> Even before 1870 we hear of [laboratory] work, not only in the laboratory of chemistry which had been especially equipped in the earlier medical buildings, but in laboratories of anatomy, physiology, pharmacy; pathology, general histology, and even in manipulation of the microscope, though were these laboratories were tucked away remains a mystery.[3]

It is definitely known that the use of the microscope was being taught at the University of Pennsylvania by 1874, for Corner stated that a physiology laboratory opened in that year: "However, the only required work in the laboratory was in histology and the use of the microscope."[4]

Extramural courses in microscope were still taught as late as 1879, in Philadelphia. The following announcement appeared in The American Naturalist:

> Microscopical Laboratory. Dr. Carl Seiler, of Philadelphia, has opened a laboratory for the instruction of students in histology, pathology, and microscopical technology. A fee of $15 is charged for a course of twelve lessons. Microscopical examinations of pathological and other specimens will be made to order, and a

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[1] Ibid., p. 245.

[2] Esmond R. Long, A History of American Pathology (Springfield, Illinois: Charles C. Thomas, 1962), p. 115.

[3] Cheyney, p. 275.

[4] George W. Corner, Two Centuries of Medicine: A History of the School of Medicine, University of Pennsylvania (Philadelphia: J. B. Lippincott Company, 1965), p. 156.

large variety of histological and pathological specimens will be prepared for sale.[1]

By 1885, the microscope had an accepted place at the University of Pennsylvania. Corner stated that the school owned enough microscopes to let every second-year student use one in the course of pathologic histology.[2]

College of Physicians and Surgeons

As has been noted in the review of the development of medical education in the United States, the second oldest medical school, although it was considered one of the best for the time, was quite slow in adopting the laboratory method of teaching. Seemingly student use of the microscope was also slow in occurring.

The opportunity for microscopical demonstrations was established early when Physiology and Microscopic Anatomy was joined under John Call Dalton (1825-1889) in 1854.[3] He taught at the College of Physicians and Surgeons until 1883. According to Meek, he established the first permanent physiological laboratory in America, but it was essentially private and not for students.[4] Rosen noted that in 1872, students at the College of Physicians and Surgeons had no opportunity to learn pathological histology or even to use a microscope.[5]

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[1]R. H. Ward (ed.), "Microscopy," The American Naturalist, XIII (1879), 697.

[2]Corner, p. 158.

[3]Theodore Francis Jones (ed.), New York University 1832-1932 (New York City: The New York University Press, 1944), p. 295.

[4]Walter J. Meek, "The Beginnings of American Physiology," Annals of Medical History, X (1928), 121-122.

[5]Rosen, p. 632.

This information was substantiated by Flexner who stated that in 1872, when William Henry Welch (1850-1934) entered the College of Physicians and Surgeons, there was no student use of the microscope. Francis Delafield (1842-1915) was an adjunct professor of pathology and clinical medicine, and he was already studying assiduously with the microscope the pathological changes in kidneys in Bright's disease. "But of opportunity for the student himself to acquire even the rudiments of the technique of the microscopic study of the organs and tissues in health and disease, there was none."[1]

Flexner reported that Welch wanted a microscope more than anything else. While he was a second year student, Edward C. Sequin (1843-1898) offered a microscope for the best report of his chemical lectures on nervous diseases. Welch won the Varick microscope which was fitted with superior French triplex lenses. "Although several of his professors were expert microscopists, it never occurred to them to pass their knowledge on to the undergraduates who should be busy memorizing the symptoms and cures of diseases."[2] Welch had to go to Europe to learn to use his microscope.[3]

Harvard

Mention is made of microscopes at this medical school long before the advent of laboratory teaching, and although direct reference

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[1]Simon Flexner, "William Henry Welch," p. 419.

[2]Simon Flexner and James Thomas Flexner, William Henry Welch and the Heroic Age of American Medicine (New York: The Viking Press, 1941), pp. 63-64.

[3]Ibid., p. 74.

to student use of the microscope cannot be found, it seems fairly evident from the available literature that demonstrations with the microscope might have been possible after 1850.

Oliver Wendall Holmes (1809-1894), a professor in the Harvard Medical School, was well-known for his microscopical research work. Between 1852 and 1860, four papers were written by him about the microscope and microscopic preparations.[1] These papers by Holmes created attention and did much both to popularize and to advance a new step in medical research. It seems only reasonable to believe that Holmes utilized the microscope at least for demonstrations in the classroom, for Brick stated: "Even though he himself was a brilliant lecturer in anatomy he insisted upon the inadequacy of verbal instruction without specimens or patients."[2] In one of his articles which was published in 1853, Holmes mentioned students and microscopes several times.[3] Long also pointed out that as Holmes was making and studying microscopic slides as early as 1850, it is believed that he demonstrated tissue abnormalities to his classes.[4]

A special course on the microscope was instituted at Harvard in 1863. The following notice appeared in The Boston Medical and Surgical Journal:

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[1]Edgar T. Brick, "A Note on the Medical Works of Oliver Wendall Holmes," Annals of Medical History, 2nd series, IV (1932), 488.

[2]Ibid., p. 489.

[3]Oliver Wendall Holmes, "Microscopic Preparations," The Boston Medical and Surgical Journal, XLVII (1853), 337.

[4]Long, n. 15, p. 403.

> Lectures on the Microscope. We would call the attention of our readers to the advertisement in this week's Journal of Dr. Holmes's lectures on the Microscope. This is the first of the new University courses of lectures in the Medical Department and cannot fail, from the well-known familiarity of the lecturer with his subject, and the charm which attaches to all his public discourses, to attract a large audience.[1]

In one of Holmes' lectures to the medical students at Harvard, he hinted at student use of the microscope. This was an introductory lecture delivered to the medical class of Harvard on November 6, 1867:

> So of personal instruction, such as we give and others give in the interval of lectures, much of it at the bedside, some of it in the laboratory, some in the microscope-room, some in the recitation-room, I think it has many advantages of its own over the winter course, and I do not wish to see it shortened for the sake of prolonging what seems to me long enough already.[2]

Although it seems evident that the microscope had been in use at Harvard for several years, it was first mentioned in the catalogue of the Harvard Medical School in 1869-1870. The delay in mentioning the microscope in the catalogue was not unusual as the stethascope had been in use for over thirty years before it was first mentioned in the 1868-69 catalogue.[3]

In 1871, laboratories of physiology and microscopic anatomy were established at Harvard.[4] Definite mention is made about the

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[1]"Medical Intelligence," The Boston Medical and Surgical Journal, LVII (1863), p. 128.

[2]Oliver Wendall Holmes, Medical Essays, 1842-1882 (Boston and New York: Houghton, Mifflin and Company, 1892), p. 291.

[3]Abraham Flexner, Medical Education in the United States and Canada, p. 8. quoting R. C. Cabot, "Sketch of the Development of the Department of Clinical Medicine," Harvard Medical Alumni Quarterly, n. v. (January, 1904), p. 666.

[4]J. Lewis Brerner and Frederick C. Shattuck, "The Medical School 1869-1929," The Development of Harvard University Since the Inauguration of President Eliot, 1869-1929, ed. Samuel Eliot Morison (Cambridge, Mass.: Harvard University Press, 1930), p. 555.

introduction of the microscope in the teaching of this laboratory.[1] Henry Pickering Bowditch (1840-1911) set up the physiology laboratory when he returned from Germany in 1871. Here his students worked with the microscope and the kymograph.[2]

Again in 1883, definite mention was made to the student use of microscopes. In 1880, Charles Sedgwick Minot taught the first class of four students of the Harvard Dental School the use of the microscope and preparation of slides.[3] He taught them the technique of histological sectioning, the use of the microscope, and gave lectures on dental histology and embryology.[4] In 1883, Minot was appointed Instructor of Histology and Embryology at the Harvard Medical School.[5] Lewis stated:

> In the year 1883, when Dr. Minot was appointed Instructor and took charge of the Department of Histology, the Harvard Medical School moved to its new building on Boydston Street - "a noble edifice," as Dr. Holmes declared, "in which you will find apartments devoted to microscopic instruction and study." These apartments included a well-lighted students' laboratory on the top floor which, according to President Eliot, was of Dr. Minot's own planning. It was equipped with eighteen Hartnack microscopes, and the department, we are told, was supported by an annual appropriation of fifty dollars, and supplemented by a gift of six hundred dollars made personally to Dr. Minot and increased by his own generosity. Additional microscopes were purchased with money borrowed from the University and in time repaid through rental fees.[6]

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[1]Long, note 14, p. 403.

[2]Corner, p. 155.

[3]Fredrick T. Lewis, "Charles Sedgwick Minot," The Anatomical Record, X (January, 1919), 145.

[4]Rosen, p. 628.

[5]Lewis, p. 146.

[6]Ibid.

Other Medical Schools

Student use of the microscope is mentioned in many histories of medical schools and other references. Many times only the date of the establishment of courses or lectures in microscopy or microscopical anatomy is given, and no mention is made as to the use of the microscope. Corner stated: "Progressive American anatomists began about the same time [that courses were instituted around 1850] to demonstrate microscopic preparations to their classes by projecting slides on the screen, or having each student in turn look through a microscope."[1] If this was the case, the microscope was probably in use long before the literature suggests. For the purposes of this present study, the other medical schools who seemingly incorporated the use of the microscope in the teaching of the medical sciences will be mentioned in chronological order.

About mid-nineteenth century some progressive medical schools began appointing professors of microscopy. In 1850, the New York Medical College was chartered and Edward R. Peaslee (1814-1878) was appointed to the Chair of Physiology, Pathology, and Microscopy in 1851.[2] The University of Georgia created a chair of comparative and microscopic anatomy in 1852; it was offered to Henry Fraser Campbell (1824-1891) who had been a demonstrator in anatomy for several years. This school as many other southern schools suffered a decline after the Civil War.[3]

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[1]Corner, p. 155.

[2]Abraham Jacobi, "The New York Medical College, 1782-1906," Annals of Medical History, I (1917), 370-371.

[3]Roger G. Doughty, "History of the Medical Department of the University of Georgia," Annals of Medical History, X (1928), 84-85.

Moses Clark White (1819-1900) was appointed Lecturer on Microscopy in the Medical Department of Yale College in 1857, and Professor of Microscopy and Pathology in 1867.[1] He was author of a treatise on the microscope, and it seems only logical to expect that he utilized the microscope in his teaching. The Yale Catalogue for 1872-73 boasted of a sufficient number of compound microscopes for "regular" instruction.[2]

An early user of the microscopes in his own pathological studies, Francis Donaldson (1823-1891), served in the latter part of the 1860's as Professor of Physiology, Hygiene, and General Pathology at the University of Maryland.[3] As early as 1853, Donaldson had published an article, "Practical Application of the Microscope in the Diagnosis of Cancer," in The American Journal of Medical Science.[4]

According to Corner, a University of Michigan professor was teaching the use of the microscope to a few students, for extra fees, about 1869.[5] This is another example of extramural courses being taught first.

It seems that when new schools were established, they incorporated the newest innovations into their curricula. The Medical School of the Pacific was opened in 1870, and Edwin Bentley (n.d.) was Professor of Descriptive and Microscopic Anatomy and Pathology. In 1874, Joseph H. Wythe (1822-1901), who was an author of many early works

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[1]William K. Kingsley (ed.), Yale College: A Sketch of Its History with Notices of Its Several Departments, Instructors, and Benefactors Together with Some Account of Student Life and Amusements by Various Authors (New York: Henry Holt and Company, 1878), II, 86.

[2]Corner, p. 155.

[3]Long, p. 116.

[4]Ibid.

[5]Corner, p. 155.

on microscopy, became Professor of Microscopy and Biology with designated responsibility for instruction in pathologic as well as normal histology and with special attention to the microscopic anatomy of tumors.[1]

The Western Reserve School of Medicine was established in Cleveland, Ohio, in 1840. Waite stated that it is probable that no microscopical demonstrations in either pathology or histology were given there before the Civil War.[2] Beginning in the early 1870's references to microscopical demonstrations began to appear which indicated that some members of the faculty must have owned microscopes.[3] "The statement is made in the catalogue beginning in 1870 that instruction in the use of the microscope was given, and beginning in 1754 that microscopical demonstrations are offered although no laboratory course in a microscopical subject was offered until 1887."[4] The catalogue of 1874, stated: "'It will be the endeavor to illustrate the lectures by practical demonstrations to show the application of physiological science and histology to practical medicine and surgery.'"[5] According to Waite, the demonstrations consisted in passing around the class a hand microscope with mounted slides.

The first record of ownership of microscopical equipment purchased for student use at Western Reserve was noted in December, 1887, when one of the professors was reimbursed to the amount of $234

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[1]Long, p. 120.

[2]Waite, Western Reserve School of Medicine, p. 112.

[3]Ibid., pp. 137-138. [4]Ibid., p. 142.

[5]Ibid., p. 189.

paid to him for eight microscopes in October, 1887. Waite quoted the following statement from the catalogue published in the spring of 1888:

> "The physiological laboratory . . . by aid of a donation of Mr. John Huntington . . . has been furnished with microscopes and other apparatus necessary for practical work. . . . Each student will be furnished with an instrument and necessary fluids and chemicals, and the class will be divided into sections . . . ."[1]

Waite explained that "this equipment was entirely for histology rather than for what we now consider physiology. Mr. Huntington gave $500 for this purpose in December, 1887."[2]

A Canadian medical school offered for the first time a course in the use of the microscope in 1875. This relatively early student use of the microscope was due to the efforts of William Osler (1849-1919) who had done microscopical research from the time of his youth. At that time at McGill Institute of Medicine, the students paid their fees directly to the instructor who provided the equipment and materials and lived on the balance. The supply of available microscopes was meager, but Osler soon remedied that. Every student was furnished a microscope which had been obtained from Hartnack's of Paris and Potsdam. By 1887, Osler had prepared a laboratory manual for students on the use of the microscope.[3]

By 1878, the Bellevue Hospital Medical College in New York City, was offering a course in the use of the microscope. When William Henry Welch returned from Europe, the school gave him three rooms which

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[1] Ibid., p. 190.

[2] Ibid.

[3] Harvey Cushing, The Life of Sir William Osler (3rd Impression, Oxford: The Clarendon Press, 1925), I, 131, 137, 193.

he used for teaching microscopical courses. He collected six antique microscopes and put six students to work.[1]

A survey of courses taught in 1890-91, in medical schools of the United States was conducted by John Rauch. The results showed that there were opportunities for the use of the microscope in medical schools at that time. Although it is impossible to ascertain the exact number of schools which permitted or encouraged student use of the microscope, the possible use of microscopes can be estimated. One hundred forty-two medical schools were included in this survey: fifty-three of the 142 offered courses in microscopy; two specifically mentioned microscopical laboratory work and one charged a three dollar fee for the lab; nine schools offered a combination Microscopy-Histology course; eighty-eight schools taught histology--six others called their course "Practical Pathology"--eight charged pathology laboratory fees; twenty schools offered a course in bacteriology of which three charged a bacteriology laboratory fee.[2]

The opportunity for either student use of the microscope or at least for microscopical demonstrations was quite wide-spread in 1890-91. It must be remembered that since many of these schools were low-quality commercial medical schools, equipment was probably meager. The schools which charged laboratory fees (eight for pathology; thirteen

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[1]Simon Flexner and James Thomas Flexner, William Henry Welch and the Heroic Age of American Medicine, pp. 112-113.

[2]John H. Rauch, Medical Education, Medical Colleges and the Regulation of the Practice of Medicine in the United States and Canada 1765-1891, Medical Education and the Regulation of the Practice of Medicine in Foreign Countries. (Springfield, Ill.: Illinois State Board of Health, 1891), passim.

for histology; three for bacteriology; one for microscopy) probably did provide microscopes for student use, but these schools represent less than ten percent of the total number of medical schools surveyed.

Summary

To establish a background for the emergence of the microscope in the American medical schools, the history of American medical education in the nineteenth century was reviewed. The nineteenth century has been called the "Dark Ages of American Medical Education." It was influenced greatly by three factors; the proprietary medical school, the two-year ungraded medical curriculum, and the country medical college. At the end of the nineteenth century there were many medical schools most of which were commercial and many poorly educated medical practitioners; eighty-nine of the 155 medical schools existing in 1908, did not require a high school education for entrance. Few students failed because the school existed on student fees. In summary, the state of medical education was very poor throughout the nineteenth century.

From the history of low-quality medical education throughout this century, it might be surmised that there was probably little or, at least, a late use of the microscope in teaching courses in the medical schools. Although information about the microscope in medical schools in the literature is quite incomplete, it can be concluded that the above stated surmise is probably correct. In examining the available literature, it seems that courses which would afford the opportunity of microscopic demonstrations such as microscopy, microscopic anatomy, histology, etc., were added to the curricula after 1850. There are a

few isolated examples of use of the microscope in demonstrations as early as the 1840's. Student use of microscopes both in laboratories designed to teach the use of the microscope and also in other laboratories such as pathology, histology, etc., does not seem to have begun until after 1870. The findings of the uses of the microscope are found in Table I. In examining the 1890-91 curricula of 142 medical schools, it was estimated that in less than ten percent of these schools students were receiving the chance to learn to use and to work with the microscope. There was opportunity for demonstration with the microscope, at least, since 108 schools offered pathology, eighty-eight offered histology, and fifty-three offered microscopy. Whether or not the microscope was utilized in this capacity can only by hypothesized.

The reasons for the apparent slow utilization of the microscope in an area of education which seems to lend itself to such a use are probably many. The greatest reason would probably be that since most of the medical schools were commercial money-making enterprises, no one was willing to spend the necessary money for the microscopes. As was indicated above, good student microscopes cost from fifty to one hundred dollars and, as the professor received from the school only the money the students paid after expenses were deducted, it is doubtful that the professors would spend such an amount on microscopes. If Flexner is correct in his assumption that many of the medical students of the nineteenth century were from the lower socio-economic classes, it is also doubtful that they could afford to buy expensive microscopes.

Another factor which probably retarded the use of the microscope was the conservativeness of the American practitioner. He was slow to accept innovations in medicine which were coming from Europe such as the

TABLE I

INTRODUCTION OF THE MICROSCOPE INTO AMERICAN MEDICAL EDUCATION

Name of School	Courses in Microscopy, Micro. Anat. Established	Demonstrations with Microscope	Extra-mural Micro. Courses	Student Use of Micro.in Other Labs	Use of Microscope Taught
Castleton Medical College, Vermont	1842	1841			
Vermont Med. College	1847	1847			
Univ. of Pennsylvania	1868	Before 1870	1841 1853 1866 1879	1885	1874
College of Physicians & Surgeons	1854				
Harvard	1863	1850		1871	1870
New York Medical College	1851				
Univ. of Georgia	1854				
Yale College	1857			1872-73	
Univ. of Maryland	1860's				
University of Michigan			1869		
Medical School of the Pacific	1870				
Western Reserve	1840's	1870's		1887	
McGill Institute of Medicine, Toronto	1875				1875
Bellevue Hospital Medical College					1875

microscope, the stethoscope, and the thermometer. Since the practitioner was the teacher in these proprietary medical schools, he would be as slow to utilize an instrument in his teaching as in his practicing.

Also because the teacher was usually a busy practitioner, he had little time to introduce innovations into the teaching of his courses. Most courses were taught by didactic lectures with the emphasis of the whole medical education being on passing the written final examination or sometimes only oral examinations. This type of situation would provide little impetus for the use of the microscope.

Therefore, it can be concluded that the microscope was used neither as frequently nor as early as it might have been. Although European medical educators were quick to utilize the microscope in teaching the new medical sciences after 1840, it probably was not until after 1870 that the microscope came into use in the United States, and then it is doubtful that it was employed in many of the commercial medical schools of that day.

CHAPTER VI

THE MICROSCOPE IN OTHER AMERICAN COLLEGES

The use of the microscope in the teaching of science in other American universities and colleges can be presented now that its role in American medical education has been discussed. Even before the nineteenth century, some colleges and universities possessed microscopes. The manner in which these microscopes were used in the eighteenth century remains a mystery. Most probably they were considered as a natural phenomena themselves rather than a tool to study other natural phenomena. They were probably exhibited when and if the microscope was described in the natural philosophy course. The advent of the microscope into American colleges during the eighteenth century will be reviewed to help establish a background for its use in the nineteenth century.

The Advent of the Microscope in the Eighteenth Century

An interest in natural philosophy began early at Harvard. Charles Morton's Compendium Physicae was adopted as a textbook shortly before Morton arrived in New England in June, 1686. This textbook pointed out the importance of experimental methods, and it gave the Harvard

student a glimpse of the "New Science."[1] A Professor of Mathematics and Experimental Philosophy was established at Harvard when a Mr. Hollis sent the college twelve hundred pounds of sterling to establish that professorship in 1726.[2]

The first microscope Harvard owned was given to the college by Thomas Hollis (n.d.). This microscope and two astronomical spheres were delivered to the college in July, 1732, with a note:

> "I have also delivered ye Captain a small shagreen case with a Double microscope and its utensils, which upon receipt, I desire you to present, with my Humble Service, to ye Corporation for ye use of ye College. I hope Mr. Professor Greenwood will make good use of each, for ye promoting useful knowledge, and to ye advancement of natural and revealed Religion."[3]

There is apparently no record of what use Professor Greenwood made of the microscope. The microscope was a Wilson screw barrel with eight objectives; in the literature it is often referred to as a box of microscopes.

The next record of a microscope given to Harvard is a copy of a thank you letter to James Bowdoin (1726-1790) dated September 4, 1758. Another thank you letter was sent April 5, 1763, to the Honorable Jon Belcher (n.d.) for a solar microscope.[4]

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[1]Charles Morton, Compendium Physicae, ed. Samuel Morrison ("Publications of the Colonial Society of Massachusetts," Vol. XXXIII; Boston: Colonial Society of Mass., 1940), p. xxxi.

[2]Frederic T. Lewis, "The Hollises and Harvard A Record of Gifts and Benefactions from England to America," The Harvard Graduates' Magazine, XLII (1933-1934), 108.

[3]Ibid., pp. 109-110.

[4]I. Bernard Cohen, Some Early Tools of American Science (Cambridge, Mass.: Harvard University Press, 1950), p. 40.

In 1775, Harvard received another microscope from Bowdoin as the college records include a note of thanks for the valuable microscope. The Harvard Corporation also resolved the following in accord with the wishes of one of the donors of apparatus:

> "That when the Glasses shall be received into the College, they shall alwaies be kept in the Library, only when the Mathematics Profess^{r} shall need them for the instruction of the pupils that attend his lectures, he may take them in to their chambers, but when the tut^{rs} or the s^{d} Proff^{r}, shall have finished their instruction^{s}, of their s^{d} pupils in the arts affore s^{d} they shall be immediately returned to the Library."[1]

Although lecture number thirty-one of Professor John Winthrop's (1714-1779) manuscript notes of 1746, was devoted to the microscope, Cohen believed that he actually made little use of them other than to have exhibited them during lectures relating to optical instruments.[2] However one of Winthrop's students, Edward Broomfield (1723-1746), a member of the class of 1742, became quite interested in and used the Harvard microscopes. After his graduation he apparently bought and made microscopes.[3] Microscopes either were given to Harvard University or were purchased throughout the century as can be implied from an inventory which was made in 1807, and in which eight microscopes were listed among the 300 items of philosophical apparatus.[4]

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[1]William Martin Smallwood with Mabel Sarah Coon Smallwood, Natural History and the American Mind (New York: Columbia University Press, 1941), p. 200 quoting from MS, Harvard University, Harvard College Records, II, 61.

[2]Cohen, pp. 110-113.

[3]Frederic T. Lewis, "The Advent of Microscopes in America," The Scientific Monthly, LVII (1943), 249.

[4]Cohen, p. 114.

A microscope was purchased by the trustees of Yale College from Scarlett of London on May 19, 1734.[1] It was a compound microscope and is believed to have been made by Matthew Loft (n.d.) since it is identical with the so-called Culpeper instrument known to have been manufactured by Loft.[2] Woodruff stated the following about this microscope:

> . . . it apparently served the college long and well. Doubtless it is the instrument listed among the possession of the College in 1747 by President Clap as "a microscope" with the apparatus; in 1779, by President Stiles when the British were threatening New Haven, as a "microscope"; still again in 1787, this time by Cutler, a visiting Yale alumnus as a "microscope of the compound kind, but very ancient"; and finally, for the eighteenth century, by Stiles in 1789 as "a microscope" among the available "machines for a course in experimental philosophy." And Stiles took the trouble to annotate the entry of a microscope in Clay's list with the comment "excellent," which he certainly would not have done if the same instrument were not extant. Indeed, he notes that various other instruments were "taken by the British" or ruined in the war.[3]

The next microscopes owned by Yale were obtained in 1789, when President Stiles ordered "a complete apparatus of optical instruments consisting of a new universal compound microscope, a solar microscope of the latest improvements, with a megalascope, and stand for Watson's microscope, the whole furnished with everything necessary for the nicest observations with the microscope.[4] How the microscope was utilized at Yale could not be found in the available literature. It is interesting to note Joseph Emerson's comment in a letter to his brother: "The

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[1]Lorande Loss Woodruff, "The Advent of the Microscope at Yale College," American Scientist, XXXI (July, 1943), 241.

[2]The Sheffield Scientific School, 1847-1947: A Catalogue of Surviving Early Scientific Instruments of Yale College (New Haven, Conn.: Yale University, 1947), p. 1.

[3]Woodruff, p. 242. [4]Ibid.

Philosophical Apparatus at Cambridge [Harvard] is by far the best, but New Haven [Yale] scholars are the best philosophers. The reason is that the scholars at New Haven are allowed to use the instruments themselves, but not at Cambridge."[1]

Smallwood stated that as early as 1767, the College of William and Mary secured both a double microscope and also a solar microscope. They were probably used at least to illustrate the natural philosophy lecture on the microscope. Smallwood presented a comprehensive outline of the lecture on the microscope given by the president of the college, James Madison (1749-1812): (1) different kinds of microscopes; (2) simple microscope; (3) the distance at which the object must be placed from the microscope; (4) why does the object appear to be magnified?; (5) the method of finding the magnifying; (6) double or compound microscope; (7) why spy glasses are generally used; and (8) the construction of solar microscopes.[2]

The faculty at Brown University evidently became interested in microscopes and other philosophical apparatus early. In 1768, the Corporation requested the President to write to Morgan Edwards (1722-1795), who was then collecting funds in Great Britain, and to ask him to "purchase an Air-Pump, a Telescope and a Microscope out of the Monies at

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[1]Harriet Webster Marr, The Old New England Academies (New York: Comet Press Book, 1959), pp. 203-204, quoting Ralph Emerson, Life of Rev. Joseph Emerson, Pastor of the Third Congregational Church in Beverly, Ms., and Subsequently Principal of a Female Seminary (Boston: Crocker and Brewster, 1834), p. 157.

[2]Smallwood, p. 202 from MS College of William and Mary, Manuscript Notebook of the Lectures of President James Madison on Natural Philosophy, 1809.

any time in his Hands by the Consent of the Donors."[1] Evidently they were successful in obtaining some of the apparatus, for the president in a letter dated February 21, 1772, wrote: "Our Apparatus consists of a pair of globes, two microscopes and an Electrical machine."[2]

Several other colleges which were founded at the end of the eighteenth century started out with microscopes as part of their apparatus. Kentucky Academy which was founded in 1796, and which merged with Transylvania College two years later had a microscope in its initial equipment.[3] Transylvania also received a microscope in 1796, when a Dr. Gordon in London raised a subscription for apparatus.[4]

Setting the Stage for the Use of the Microscope

Many factors influenced the introduction of the use of the microscope into the teaching of science. These factors which are broadly summarized are the philosophy of education which prevailed in the nineteenth century; the establishment of the scientific schools, scientific courses, summer schools, the land-grant colleges, among others; the changing emphasis of both biological research and also the teaching of biology in the American colleges and universities; and the influence of the normal schools and the object method of teaching.

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[1]Walter C. Bronson, The History of Brown University 1764-1914 (Providence, Rhode Island: Brown University, 1914), p. 106.

[2]Ibid., p. 107.

[3]Thomas Cary Johnson, Scientific Interests in the Old South (New York: D. Appleton-Century Company Incorporated, 1936), p. 35.

[4]Walter Wilson Jennings, Transylvania: Pionner University of the West (New York: Pageant Press, 1955), p. 30.

The Philosophy of Education in the Nineteenth Century

The philosophy of education which dominated nineteenth century higher education was clearly alluded to in the Yale Report of 1828, the most influential educational publication issued between the Revolution and the Civil War. The Yale Report outlined the educational program which was followed by the American colleges throughout most of the nineteenth century. The prescribed curriculum which featured a thorough study of the ancient languages was justified on the basis of faculty psychology which was a concept of mental disciple. The aim of the college was to lay a general foundation common to all professions through a course in the liberal arts. It was felt by the authors of the Yale Report that the undergraduate could not select for himself because he was not mature enough to realize what branches of knowledge were the common foundations of all high intellectual attainments.[1] The subjects of the curriculum were chosen for their value in intellectual discipline rather than for the practical knowledge they might impart. The curriculum contained no more content than each student could master in the allotted four years.[2]

In making the decision for prescribing those subjects in the curriculum that would furnish mental training, Turner feels that the nineteenth century educators divided the studies into permanent and progressive studies; the permanent studies were considered to be ancient

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[1]John S. Brubacker and Willis Rudy, Higher Education in Transition: An American History 1636-1966 (New York: Harper and Brothers Publishers, 1958), p. 101.

[2]R. Freeman Butts, The College Charts Its Course (New York: McGraw-Hill Book Co., Inc., 1939), p. 127.

languages and geometry, whereas chemistry, botany, and geology were considered to be the progressive studies. It was felt in the nineteenth century that the permanent studies should be taken first; the emphasis should be on those permanent studies which would expand powers of the mind and would, therefore, provide the student with a liberal education.[1]

Youmans, a writer who popularized science in the latter part of the nineteenth century, also explained: "By mental discipline in education is meant that systematic and protracted exercise of the mental powers which is suited to raise them to their highest degree of healthful capabilitity, and impart a permanent direction to their activity."[2] Youmans also explained that the traditionalists believed the purpose of a liberal education was not to prepare for a vocation or profession but rather to train the intellectual faculties. Mental discipline was the true object of a higher culture and was thought by the traditionalists to be attained best by the study of ancient classics and mathematics.[3] Youmans proceeded to argue for the inclusion of the sciences into the curriculum on the same basis Herbert Spencer was using in England: the sciences also help train the faculties of the mind and therefore, for their mental discipline ability they should be included in the curriculum. Youmans stated that scientific education provides a systematic

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[1]D. M. Turner, "The Philosophical Aspect of Education in Science," Isis, IX (1927), 402.

[2]E. L. Youmans, "Introduction of Mental Discipline in Education," The Culture Demanded by Modern Life: A Series of Addresses and Arguments on the Claims of Scientific Education, ed. E. L. Youmans, et al. (New York: D. Appleton and Company, 1881), p. 12.

[3]Ibid., p. 2.

exercise of the observing powers and that the physical sciences teach deduction.[1]

In order to include the sciences as part of the curriculum even for its value to train the faculties, an elective system or a partial elective system had to be introduced into the American colleges. Several attempts were made throughout the nineteenth century; Francis Wayland (1796-1869) attempted a reform at Brown in 1842, and Henry Phillip Tappen (1805-1881) attempted a reform at the University of Michigan in 1851, but both attempts were unsuccessful, and both men were forced to resign.[2] It was not until 1869, that an American college president succeeded in introducing the elective system. Charles W. Eliot (1834-1926), who was a chemist educated in Germany, by introducing the elective system into Harvard in 1869, made possible a tremendous expansion and broadening of American college curricula.[3]

This occurred about the time the influence of the German university was being felt in American higher education. Some of the thoughts emanating from German higher education included: (1) institutions of true higher learning should be workshops of free scientific research, (2) a freedom of learning should prevail; (3) students should take whatever courses they wished; (4) professors were free not only to investigate all problems in the course of their research but also were free to reveal their findings in both their teaching and in their

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[1] Ibid., pp. 25-28.

[2] Brubacker and Rudy, pp. 103-104.

[3] Ibid., pp. 107-112.

published works. American students who flocked to Germany after the Civil War returned with these ideas and introduced them into American higher education.[1]

At the same time, the latter third of the nineteenth century, a change in educational philosophy was occurring. The beginnings of an experimental psychology threatened to destroy the theoretical bases of mental discipline. This new area of knowledge provided, and even demanded, a place in the curriculum for the sciences and, above all, for the experimental teaching of these scientific courses.[2]

Both the prevailing philosophy of mental discipline and the belief in a prescribed curriculum of ancient languages and mathematics had much influence on the slow adoption of the microscope to teach science. Science courses had to be an accepted part of the curriculum before the microscope could be utilized. The educational philosophy which prevailed was to have much effect on the teaching of science and on the subsequent use of the microscope.

Establishment of Separate Schools and Courses to Teach Science

Although the traditional curriculum of liberal education established by the Yale Report of 1828, dominated American colleges throughout most of the nineteenth century, at the same time there was a realization for the need to teach scientific courses in the United States, and that need was met in a variety of ways. The nineteenth century American society was a utilitarian, democratic, and, above all,

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[1] Ibid., p. 171. [2] Butts, p. 161.

pragmatic society which demanded that the science and technical courses be instituted in some manner.

First, independent technical schools were established in complete isolation from any established college. One of the first, Rensselaer Polytechnic Institute, one of the most progressive institutions of its time, was established in 1824, in Troy, New York. The Worcester Polytechnic Institute and the Massachusetts Institute of Technology, established in 1865, were two other institutions founded to meet the need for scientific and technical education.[1]

Scientific schools were established alongside some of the traditional colleges to care for "practical minded" students. Lawrence Scientific School was established by Harvard in 1847; Sheffield Scientific School by Yale in 1847, and Chandler Scientific School by Dartmouth in 1852. Unfortunately, these schools were believed to be inferior to the rest of the college and were looked upon with contempt by the "regular" students and professors.[2]

In some colleges, parallel courses were set up within the framework of traditional colleges to give students a chance to study scientific and literary subjects. For example, Brown created a Department of Practical Science in 1852, and the Department of Mines, Arts, and Manufacturers was established at Pennsylvania in 1855.[3]

The land grant colleges were another group of institutions which gave impetus to the study of scientific and technical courses.

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[1] Ibid., p. 129.

[2] Brubacker and Rudy, p. 62.

[3] Ibid.

Although they were first made possible by passage of the Morrill Act in 1862, it was much later in the nineteenth century before they were really effective. At first these institutions were hampered with inadequate funds, meager equipment, a shortage of qualified personnel to teach the agricultural and mechanical courses, and an insufficient body of knowledge. Many writers of educational history are enthusiastic about the contributions of the land grant colleges to American higher education. Brubacker and Rudy stated that the land grant colleges were among the first institutions in the United States to welcome applied science and the mechanic arts and to give these subjects a recognized place in the college curriculum. They fostered an emancipation of American higher education from a purely classical and formalistic tradition.[1] Ross stated: "No feature of the land-grant system of instruction and research has been more characteristic than the full laboratory method; the direct participation in the fullest and latest equipped laboratory, shop, field, barn . . . ."[2]

The many summer schools which were first established around 1870, also provided the student with the opportunity to study science. Although the primary design of summer schools was "to furnish teachers, therefore, with instruction in the various departments of natural science," they also served to allow the student enrolled in the classics courses to become fully acquainted with the sciences.[3]

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[1] Ibid., p. 64.

[2] Willis Ross, "Contributions of Land Grant Colleges," A Century of Higher Education, ed. William W. Brickman and Stanley Lehrer (New York: Society for the Advancement of Education, 1962), p. 103.

[3] [C. F. Thwing], "Summer Schools," Harper's New Monthly Magazine, LVI (March, 1878), 501-502.

Biological Research and Teaching

Whether or not the microscope was utilized in the teaching of biology during the nineteenth century also depended both upon the type of biological research conducted by the investigators of that period and upon the teaching of the biological sciences which in turn reflected the type of research.

The investigators of biological phenomena in the United States were much slower in turning their attention to morphological areas of research such as embryology and cytology than were the Europeans who had been pursuing these areas of research since 1830. Perhaps, until 1870, zoology research continued to be descriptive. For several reasons, the gross anatomy-natural history-taxonomy phase of zoology continued for a longer period of time in the United States than it did in Europe. First, there were still many unknown species in America. Second, Louis Agassiz, a naturalist, was in the United States and was the leader of the American natural historians.[1]

Botany remained as a study of external structure, identification of flowering plants, and so on until late in the nineteenth century. It was not until after the 1870's that internal morphology of plants was studied in the United States.[2]

As was stated above, this type of research directly affected what was being taught in the colleges. Downing divided the history of

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[1]Paul Livingstone Hollister, "Development of the Teaching of Introductory Biology in American Colleges" (unpublished Ph.D. dissertation, George Peabody College for Teachers, 1939), p. 80.

[2]Ibid., p. 61.

zoology instruction into four periods. First, the physiology period extended from 1848 to 1860. Agassiz and Gould's Principles of Zoology was the common textbook of the period. The emphasis was on the systematic distribution of animals into classes, families, genera, and species.[1] The second period, the natural history period extending from 1860 to 1875, was comprised of the study of habits and correlated structures with the emphasis largely on external structures. Tenney's Natural History and Hooker's Elements of Zoology were the favored textbooks of the period.[2] The classification period, extending from 1875 to 1886, was dominated by external and internal morphology.[3] Here for probably the first time was the opportunity to utilize the microscope in the teaching of zoology. The fourth period was the evolution period from 1886 to 1900. The animals were studied as a selected series of types to illustrate the successive advances in complexity which had supposedly come about by the process of evolution. The period was marked by the laboratory manual guiding the study of internal morphology. Parker and Haswell's Manual of Zoology was the leading textbook of this period.[4]

An examination of the popular botany textbooks of the nineteenth century reveals the emphasis of botannical teaching of the period. Wood's Class Book of Botany, published in 1856, was widely used. Examination of the table of contents confirms that the botany of that period was principally taxonomy. It includes: Plan of Vegetation,

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[1]Elliot Rowland Downing, Teaching Science in the Schools (Chicago: The University of Chicago Press, 1925), p. 9.

[2]Ibid.

[3]Ibid., p. 12.

[4]Ibid.

Elementary organs, Primary Divisions of the Vegetable Kingdom, of the Flower, of Its Parts and Their Arrangement, etc. No mention is made of the use of the microscope in studying botany.[1] In the 1880 edition of this book, the microscope is referred to several times. The emphasis of this edition was on the cell and elementary tissues. In the preface, Wood stated:

> Botanical Apparatus. The publishers (Messrs. A. S. Barnes and Co.) have recently provided and have on sale, suitable apparatus for the use of the student in Botany, made according to directions in this work (page 15). It consists of a knife-trowel for digging and cutting specimens; a microscope and tweezers for the examination of them; a tin box for collecting and preserving them fresh, and a press for drying them. The set is securely packed and sent by express to order, at a moderate price.[2]

As physiology was widely taught in the latter part of the nineteenth century, it might be deduced that the use of the microscope became prevalent with the introduction of this course. However, this course was introduced to prepare teachers for the teaching of "physiology" in the common schools. As a result of a deliberate effort of the Women's Christian Temperance Union, there were laws in practically every state and territory of the United States before 1900 requiring instruction in temperance. Therefore "physiology" consisted primarily in teaching the

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[1]Alphonso Wood, A Class-Book of Botany, Designed for Colleges, Academies and Other Seminaries. In Two Parts. Part I. The Elements of Botanical Science. Part II. The Natural Orders. Illustrated by a Flora of the Northern, Middle and Western States Particularly of The United States North of the Capitol, Lat. 38° (41st ed. rev. and enlarged; Boston: Crocker and Brewster, 1856), passim.

[2]Alphonso Wood, Class-Book of Botany: Being Outlines of the Structure, Physiology, and Classification of Plants; with a flora of the United States and Canada (New York: A. S. Barnes and Co., 1880), p. ii.

effects of alcohol on the human body.[1] It is doubtful that the microscope was utilized or needed to teach this.

Normal Schools and Object Training

A powerful stimulus to the teaching of science and the subsequent use of the microscope was furnished by the normal schools of the nineteenth century. The normal schools were not bound to the traditional liberal education of other colleges of that period. As Kuslan stated, both normal and secondary schools believed that science was a powerful instrument for building a firm belief in God. Both were certain that science would better prepare students for the practical world of everyday life; both insisted that science sharpened the powers of perception, memory, generalization, and reason. The major purpose of the normal schools established from 1839 was to prepare competent teachers for the common schools, and although science was seldom taught in the elementary school, all normal school students learned science by teaching it to their classmates.[2]

This practice can be traced back to the methods of the Rensselaer Polytechnic Institute. The laboratory method and student teaching were introduced in this school as will be discussed below. It is interesting to note that one of the reasons for the founding of this school was to create teachers of science. Stephen Von Rensselaer (1764-1839) wrote the

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[1]Thomas Harold Glover, "Development of the Biological Sciences in Teachers Colleges of the Middle West" (unpublished Ph.D. dissertation, George Peabody College for Teachers, 1940), pp. 148-150.

[2]Louis I. Kuslan, "Science in the 19th Century Normal School," Science Education, XL (1956), 139-141.

following in a letter dated November 5, 1824:

> I have established a school in the north end of Troy, for the purpose of instructing persons, who may choose to apply themselves, in the application of science to the common purposes of life. My principal object is to qualify teachers for instructing the sons and daughters of farmers and mechanics, by lectures or otherwise, in the application of experimental chemistry, philosophy and natural history to agriculture, domestic economy, the arts and manufactures.[1]

The instrument used to teach the sciences in the normal schools was object teaching. In the 1847 volume of The American Journal of Education is a translation of Diesterweg's "Catechism on Method of Teaching" in which he stated the method of instruction is the mental development of the object. Three steps, observation, conception, and generalization, make up this developing method.[2]

Beale, although he taught medical students, described object teaching in The American Naturalist in 1868.

> Object Teaching in Natural Science. I am strongly of opinion that it is more necessary than ever that we should teach as much as possible by the eye. In teaching any branch of natural science, the demonstration should be combined with oral teaching. The student should see what is described, and where it is not possible for the teacher to exhibit illustrative specimens, good models, drawings, and explanatory diagrams should be supplied. It is the duty of every teacher to study how to communicate knowledge most easily and most clearly, and to save the student as much time as possible; . . . . A lecturer on every branch of microscopic inquiry can now show his pupils the structures he describes. For the last three years I have carried out this plan myself and have

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[1]Palmer C. Ricketts, Amos Eaton, Author, Teacher, Investigator: The First Laboratories for the Systematic Individual Work of Students in Chemistry, Physics and Botany, to be Created in Any Country: B. Franklin Greene and the Reorganization in 1849-50 ("Rensselaer Polytechnic Institute: Engineering and Science Series," No. 45; Troy, New York: Rensselaer Polytechnic Institute, 1933), p. 8.

[2]Ed Hintze, "Natural History," trans. Hermann Wimmer, The American Journal of Education, IV (1857), 240.

> found that it works admirably. I am able to demonstrate from eight to twelve microscopical specimens to a large class in the course of an hour, ...[1]

The object method of teaching was introduced into the American normal schools as "The Oswego Movement" or "The Oswego Plan" under the leadership of E. A. Sheldon. The Oswego Normal School was founded in 1861, and Pestalozzian principles, object teaching, and an emphasis on sense perception were introduced.[2] It would seem that this method of teaching plus the emphasis on the science courses in the normal schools would encourage the use of the microscope. However, the normal schools were state-supported and therefore poor; this condition seemingly would deter the use of the microscope despite the impetus of the method of teaching.

The Use of the Microscope in the Science Classroom

The stage has been set, and now the use of the microscope can be examined in light of the foregoing discussions. To determine when and in what capacity the microscope was used, certain artificial divisions or periods of science education have been adapted for the purposes of this paper. Louis Kuslan arbitrarily divided science teaching into divisions according to the methods of science teaching.[3] First, natural

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[1] Lionel S. Beale, "Object Teaching in Natural Science," The American Naturalist, I (1868), 159.

[2] Ned Harland Dearborn, The Oswego Movement in American Education ("Teachers College, Columbia University: Contribution to Education," No. 183; New York City: Teachers College, Columbia University, 1925), p. 1.

[3] Louis I. Kuslan, "Science in Selected Normal Schools of the 19th Century," (unpublished Ph.D. dissertation, Yale University, 1954), passim.

philosophy and natural history were probably taught by recitation as other courses were taught in the eighteenth and even into the nineteenth century. The student studied the textbook and subsequently was questioned over the assignment.

The next stage of science teaching was probably the lecture-demonstration method. Along with the lecture, the professor provided a demonstration in order both to illustrate and to explain his lecture.

Kuslan designated the next stage of advancement as the analytical-concept stage. This is actually just a step above the lecture demonstration when more demonstrating was done, and more use of objects was made. The demonstrations were performed by some of the students as well as the instructor. This was an adult "object" method which had been popularized by followers of Pestalozzi on the elementary level of teaching.

The final stage would be the laboratory method of teaching of science. In this method, each individual takes part in actual experiments. He does the work rather than watching someone demonstrate it for hom.

It must be pointed out that none of these periods covers a specific time interval. Although they occurred more or less successively during the nineteenth century, one institution might have been teaching science by the laboratory method while a neighboring institution was still relying on the recitation form of teaching.

Therefore, in order to ascertain the role of the microscope in the college classroom, it will be necessary to classify its use according to the last three arbitrary divisions: lecture-demonstration,

analytical-objective method, and laboratory teaching. There are many ways of determining the method of science teaching used when mention is made of the use of the microscope. First, the method of science teaching is often described. Second, if the method of teaching is not indicated, a course description is given, and from the basis of the previous discussion, implications can be drawn from internal evidence.

As was stated above, the distinction between the lecture-demonstration and the analytical-objective methods is very fine, and often it is difficult to ascertain which method of teaching was being utilized. For the purposes of this study, if only one or two microscopes were mentioned, it was assumed that the lecture-demonstration method was being used; if three or more microscopes were mentioned, it was presumed more students were taking part, and it thus could be classified as teaching by the analytical-objective method. This arbitrary division was used by the author only when it is clear that the laboratory method of teaching was <u>not</u> being used.

Classifications and divisions are always artificial and are primarily used for convenience in establishing some order. They do serve this function, and therefore this particular classification will be used to survey the use of the microscope as a tool in the teaching of science.

First, examples of the place of the microscope as it was used in the lecture-demonstration method of teaching science will be presented. Then the uses of the microscope incorporated in the analytical-objective method of teaching will be studied. Finally, the use of the microscope in the laboratory, and the consequent development of special

instruction and individual courses concerning the microscope itself will be discussed.

Microscopes Used in the Lecture-Demonstration Method of Science Teaching

The introduction of the microscope into American colleges during the eighteenth century has been reviewed. There was no abrupt change during the transition from the eighteenth to the nineteenth century; there was a continuation of the introduction of the microscope with other philosophical apparatus during the early part of the nineteenth century. In 1796, John Maclean (1771-1814), a young Scotch chemist who had studied at Glasgow, Edinborough, London, and Paris, was appointed to the Chair of Natural Philosophy and Mathematics at Princeton. Philosophical apparatus was ordered from an agent in London. The barometers, thermometers, two pairs of nine-inch globes, an astronomical quadrant, "magnetical apparatus," a magic lantern, an air pump, a "fountain in vacua," a "lungs glass," an artificial eye, a "hydrostatical apparatus," an opaque and transparent microscope, a three-and-a half-foot telescope, and a four-foot reflecting telescope arrived in the early 1800's. The manner in which this apparatus was utilized is not described, but most probably it was exhibited in order to demonstrate the apparatus referred to in the natural philosophy lectures as was apparently done during the eighteenth century.[1]

James Blythe (1765-1872), professor of natural philosophy at Transylvania University in Lexington, Kentucky, purchased a solar

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[1]Thomas Jefferson Wertenbaker, Princeton 1746-1896 (Princeton, New Jersey: Princeton University Press, 1946), p. 124.

microscope for forty-five dollars on May 1, 1805.[1] This microscope was evidently used to demonstrate lectures on biological subjects for according to Johnson:

> The manner in which the solar microscope was to be used for the edification and pleasure of the students is shown by a memorandum dated 1805 and headed "Solar Microscope . . . A List of Objects in 5 Sliders." This memorandum describes 6 slides or "sliders to be viewed under the microscope, five of which had been prepared, the sixth 'to be filled at pleasure.'" On number one, there were down of a moth, farina of a sunflower, down of a thistle, and seed vessels of a sorrel. Slide number 2 contained sassafras, virgin's bower, elm-root, and cane. On the third slide there were "wing of a libella, do of a bee, do of a stone fly, do of a beetle." The fourth contained a louse, a flea, a dissected leaf, and seaweed; and the fifth had four fish-scales: perch, sole, race, and gudgeon.[2]

The academies of the late eighteenth and early nineteenth centuries taught natural philosophy and purchased philosophical apparatus among which the microscope was sometimes mentioned. In 1798, the Leicester Academy in Massachusetts boasted of "a prospect glass, a microscope, an electrical machine, a thermometer, and a set of instruments for surveying land."[3] Joseph Emerson (1777-1833) was probably using the microscope to illustrate his natural philosophy classes around 1826, as Marr stated:

> What proof have we that teachers were really using this new equipment effectively? Surely the great teachers of the 1830's employed such apparatus competently. Joseph Emerson in his famous 1826 prospectus of Wethersfield Female Seminary wrote under Natural Philosophy that the method should be "analytic, not synthetic. First present facts or experiments, then inquire for

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[1]Smallwood, p. 203.

[2]Johnson, p. 36.

[3]Marr, p. 206.

> the principle." He spoke of "experiments with greatest possible simplicity and economy, that they may be easily performed by such of my pupils or may have occasion to illustrate the same principles. No need of expensive articles, formed exclusively for that purpose. Any mechanic's tools, kitchen utensils, etc. Have an air pump, a few vessels in connection, electrical machine, telescope, microscope, and a little orrery."[1]

Microscopes were beginning to enter into the enlargement and advancement of biological knowledge by 1831. Although no specific mention was made to demonstrations with the microscope, Smallwood stated that John Patten Emmet (n.d.) of the University of Virginia was incorporating into his lectures about the biological revelations of the microscope in 1831.[2]

In 1831, Phillip Fall (n.d.) founded a college, The Kentucky Female Eclectic Institute, near Frankfort, Kentucky. He had purchased a considerable quantity of apparatus in London and Paris. Evidently the college did not last too long as the Board of Bacon College, also in Kentucky, bought Fall's apparatus in 1857, for $4,500. In 1864, Bacon College merged with Transylvania University and together they eventually became the University of Kentucky. The Fall apparatus included a grand cal-oxhydrogen microscope which cost $910, a superior compound microscope valued at $80, a Lucernal microscope worth $100, and a Raspail aquatic microscope. With the Lucernal microscope came a large collection of natural history objects which could be viewed with that microscope. Most of the objects were parts of insects and sections of well-known plants and trees. A machine for making wood cuttings for the

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[1] Ibid., p. 207.

[2] Smallwood, p. 204.

microscope was also purchased for $18.[1] It would seem probably that these microscopes were used to demonstrate biological specimens in natural history or natural philosophy classes.

One of the first references to the purchase of philosophical apparatus for Harvard during the nineteenth century is given by Dupree. He stated that in 1844, the corporation voted to allow Asa Gray (1810-1888) to spend seventy-two dollars for "several microscopes to be used by the Students of Botany."[2] Dupree stated that Gray had a desire for laboratory instruction. However the plight of laboratory instruction at Harvard between 1849 and 1853 is noted by Eliot:

> When I was a student in the Harvard College, there was not a single laboratory open to the students on any subject, either chemistry, physics, or biology. The only trace of such instruction open to students was in the department of botany, and that was only for a few weeks with a single teacher, the admirable botanist, Asa Gray, and he had neither apparatus[3] nor assistants, and it was a hopeless job which he undertook for a few weeks in May and June. I was the first student who ever had the chance to work in the laboratory in Harvard College, and that was entirely due to the personal friendship of Prof. J. P. Cook, who fitted up a laboratory in the basement of University Hall, entirely at his own expense.[4]

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[1]Leland A. Brown, Early Philosophical Apparatus at Transylvania College (Lexington, Kentucky: Transylvania College Press, 1959), pp. 11-16. See Appendix for a complete description of the early microscopes and slides at Transylvania.

[2]A. Hunter Dupree, Asa Gray 1810-1888 (Cambridge, Massachusetts: The Belknap Press of the Harvard University Press, 1959), p. 1 quoting from Harvard College Records, X (1844), 64 (Harvard University Archives.)

[3]Perhaps Eliot did not know of the microscopes which had been purchased for students of botany or perhaps he did not consider so few to be nearly adequate.

[4]Charles W. Eliot, "Laboratory Teaching," School Sciences and Mathematics, VI (November, 1906), 703.

Another example of the use of the microscope used to demonstrate lectures is found at the Rochester Collegiate Institute. In 1848, Dewey wrote in the Annual Report of the Regents the following:

> Our double microscope was a large one of the common construction, with several object glasses and different magnifying powers, and considerable variety of apparatus attached to the instrument. It showed the wings, eyes, hairs, etc., of insects much magnified, their bones, structures, and the like. But it could only indicate the fossil infusoria. As these have become a subject of so high interest, and I wished to show the classes in philosophy and chemistry the splendors of the minute universe as well as the magnificence of the stellar creation, Mr. Spencer of Canastota, added to it an achromatic object glass and an eye glass, so as greatly to increase its magnifying power. The instrument now ranks with the highly improved microscopes of the day. It magnifies 700 to 800 times in diameter, as many thousand times in area. It shows the fossil infusoria of the size depicted by the writers on that subject. It shows the blood corpuscles in great abundance and perfection. The small bones in the wing of the common fly are altogether too large to be seen by it. The minute crystals of salt show finely. No class of pupils can use it without admiration.
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> It is matter of congratulation that we have an artist, who is capable of more than rivalling the finest microscopes of Europe. I may be permitted to refer my fellow teachers who need such an instrument, to Chas. A. Spencer, of Canastota, in our State.
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> It is too late in the day to state the value of apparatus in illustration of the subjects of philosophy and chemistry. It is only to be regretted that it is not far more common and abundant in schools and academies. The injury and waste of it is indeed great, when employed by unskillful hands or inexperienced ones.[1]

At the middle of the century, several other schools obtained or were contemplating buying microscopes. The Columbia Female Institute was given a compound microscope mounted on a stand with slides in 1849.[2] In 1855, the Massachusetts Board of Education invested fifty dollars apiece in compound microscopes--one for each normal school in the

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[1]Chester Dewey, "Rochester Collegiate Institute," Annual Report of the Regents of the University (New York City: University of the State of New York, 1848), p. 169. Xerox copy of p. 169 available.

[2]Johnson, p. 122.

state.[1] Professor Alexander Winchell (1824-1891) of the University of Michigan wrote to Jacob Whitman Bailey (1811-1857), an authority on the use of the microscope, in 1856, wishing to know what constituted a complete microscope and asked directions for the use of the instrument. Smallwood quoted from the original letter:

> "I take the liberty of addressing a few enquiries to you in regard to the qualities of microscopes. This institution will probably soon order the purchase of a first rate Achromatic Microscope and I wish to obtain your recommendations to lay before our Board of Regents at their meeting in March."[2]

As might be expected with the opening of the special scientific schools, the microscope began to play a more important part in the teach- of science. At Harvard's Lawrence Scientific School, Asa Gray had a greater opportunity to teach botany with more practical work. In 1856, it was announced that in botany "Professor Gray will give during the Second term a course of instruction in Structural Botany and Vegetable Anatomy--with microscopical demonstrations."[3]

There is a possibility that the microscope was used to demonstrate histology which was taught by Henry James Clark (1826-1893) at the Museum of Comparative Zoology at Lawrence in 1861. A friend of Clark's wrote: "I remember his interesting lectures before our small class on cellular structure in plants and animals. His skill with the

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[1]Kuslan, "Science in Selected Normal Schools of the 19th Century," p. 683.

[2]Smallwood, p. 205 quoting MS, Boston Society of Natural History, letter, A. Winchell to J. W. Bailey, University of Michigan, Ann Arbor, Feb. 8, 1856. In Bailey, Bound MS Letters, Vol. II, No. 50.

[3]"Lawrence Scientific School," The American Journal of Education and College Review, I (January, 1856), 222.

microscope and his rare ability to draw aided him greatly in making out the minutest details of cell structure."[1]

Mention of microscopical demonstrations at Harvard is also made by W. J. Beal (1833-1924) who was a student there during the period of 1862-65. Beal stated recitation covering Gray's First Lessons in Botany, the textbook, was held without set laboratory work. "During one spring Dr. Gray met three of us for lessons in this textbook freely illustrated by fresh specimens. The botanical department at Harvard did not own a compound microscope, it had the use of a thousand dollar instrument belonging to Lowell Institute. A little crude work was done, such as viewing the streaming motion of granules of chlorophyll in leaf-sections of Valisneria, looking at grains of pollen sections of ovules, etc."[2]

During the 1860's, other schools were also beginning to use the microscope for demonstration purposes. Oswego Normal School was established in 1867, and "Oswego from its first days of state recognition (1867) owned a large 'Natural History' room boasting a microscope and case valued at some three hundred and sixty-eight dollars, a large sum for those days and for those normals."[3]

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[1]Frederick Tuckerman, "Henry James Clark: Teacher and Investigator," Science, XXXV (May 10, 1912), 726.

[2]Ernst A. Bessey, "The Teaching of Botany Sixty-Five Years Ago," Iowa State Journal of Science, IX (January, 1935), 229, quoting W. J. Beal.

[3]Kuslan, "Science in Selected Normal Schools of the 19th Century," p. 633 citing from the Annual Report of the Executive Committee of the Oswego State Normal School, 1866, pp. 25-28.

Use of the microscope in demonstrations to illustrate lectures on microscopy also occurred during the 1860's. The following announcement was published in the 1868 issue of The American Naturalist:

> Practical Microscopy. Rev. E. C. Bolles, an unsurpassed lecturer on the subject, has consented to give instruction in microscopy at the second session of the summer school of biology, which will be opened at the Museum of the Peabody Academy of Science, at Salem, Mas., on the 7th of July next. The term lasts seven weeks. A course of lectures and demonstrations on Animal Histology will also be given by Mr. C. S. Minot. The admission fee is $15.00."[1]

In 1871, Charles Edwin Bessey (1845-1915) began teaching botany at the Iowa State College. He was one of the early educators to pioneer teaching by the laboratory method. His facilities were limited because during the first year he had but one microscope. He probably made full use of it in demonstrating his botany lectures. Pool stated:

> Bessey used to tell me how excited he was when the regular school year opened on this [Iowa State College] campus in February, 1871, and he introduced his class to laboratory work in botany. The laboratory was a small room at the end of a corridor in the old main building. A label, "Botanical Laboratory," nailed on the outside of the door to that room, is said to have stimulated unusual emotions on the campus. The equipment consisted of rough board tables, a single compound microscope, for which the college paid $1,200, and a few reagents on shelves.[2]

Thomas J. Burril (1839-1916) was teaching botany at the Illinois Industrial University which was a part of the University of Illinois in 1871. Although no laboratory work is shown or described in the school catalogue for that year, there is a description of the second term's work in Systematic Botany in lectures. The use of the microscope is mentioned

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[1] "Microscopy," The American Naturalist, I (1868), 379.

[2] R. J. Pool, "The Evolution and Differentiation of Laboratory Teaching in the Botanical Sciences," Iowa State College Journal of Science, IX (January, 1935), 231.

in the description; most probably then, the microscope was being used to demonstrate the botanical lectures.[1]

About this time, the microscope was becoming a popular subject for lectures to interested audiences. The microscope was used to demonstrate these talks. The following announcement was published in the 1872 issue of The American Naturalist:

> We take pleasure in drawing attention to the Essex Institute course of eight lectures entitled "Eight evenings with the Microscope," now in course of delivery in Salem, by Rev. E. C. Bolles. The subjects are "With the Microscope Maker," "In the Laboratory," "In the Garden," "In the Forest," "By the Pondside and Seaside," "Among the Insects," "With the Zoologist," "With the Polariscope and Spectroscope." These subjects are most clearly, pleasantly and ably handled by the lecturer. The illustrations enlarged by the microscope and thrown upon a screen twenty-five feet in diameter, by aid of two powerful calcium lanterns, are simply splendid, and we doubt if more finely illustrated lectures for a popular audience has ever been presented in this or any other country.[2]

Microscopical demonstrations began at the normal school in Forbes, Illinois, in 1873. A microscope was purchased and was used to demonstrate biology classes. A second hand microscope was first purchased in 1885, for the Peru Nebraska Normal School even though the school opened in 1867.[3] As late as 1885, the microscope was also first utilized to demonstrate lectures at the University of North Carolina. Cathcart stated that three lectures a week were given on comparative anatomy, physiology, respiration, and the circulation of the blood. The lectures

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[1] Bessey, p. 231.

[2] "Notes," The American Naturalist, VI (1872), 783.

[3] Glover, pp. 181-182.

were illustrated with microscopic exhibitions of some of the lower forms of animal life.[1]

It can now be seen that the microscope was used to demonstrate lectures on natural philosophy, natural history, and biology throughout the nineteenth century. Each decade saw the adoption of this tool to be used in this manner by different colleges.

Analytical-Objective Method

As this method has been defined above, the colleges which used three or more microscopes, but still did not teach the courses by the use of the laboratory method will be discussed chronologically as in the preceding section. This type of teaching occurred at a noticeably later period.

Apparently an increased degree of use of the microscope was occurring, or at least the microscope was being recognized as an important tool in the study of science at Harvard, for during the college year of 1871-72, Professor Nathaniel S. Shaler (1841-1906) had in zoology the assistance of Albert H. Tuttle (1844 - ?) who was Instructor in the use of the microscope.[2] As the laboratory method *per se* was not mentioned and had not been adapted, it is assumed that this course was taught more as a lecture course but with some practical work obviously included.

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[1]Maude Eola Cathcart, "The Historical Development of the Teaching of Biology in the Carolinas" (unpublished Ph.D. dissertation, George Peabody College for Teachers, August, 1939), p. 59.

[2]Edward Laurens Mark, "Zoology, 1847-1921," *The Development of Harvard University Since the Inauguration of President Eliot, 1869-1919*, ed. Samuel Eliot Morison (Cambridge, Mass.: Harvard University Press, 1930), p. 383.

The Michigan State Normal College at Ypsilanti, founded in 1849, was presenting courses in structural botany and zoology by the 1870's. These were taught "partly by the laboratory method." Use of the compound microscope was available at this time according to Phelps.[1]

More work with the microscope was planned at the Illinois State Normal University in 1875. Systematic and structural botany, cryptogamic botany, systematic zoology, and comparative anatomy were all going to be taught. The president in his report to the State Board of Education stated: "A sufficient number of good microscopes have been secured for the use of students in the study of histology and the lower forms of life."[2]

As early as 1876, H. H. Straight (1846-1885) in teaching botany was stressing microscopic work at Oswego Normal School. In teaching botany, the students made the usual plant analysis and comparative study plus microscopic sections of various structures. There were only four microscopes available for this work; two of them belonged to Straight.[3] He also taught zoology and apparently he used the same four microscopes for the students to look through while the rest of the class dissected. Kuslan stated there were from sixty to 150 students in this class.[4]

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[1]Jessie Phelps, "A Brief History of the Natural Science Department of the Michigan State Normal College 1849-1949," (Xerox copy of unpublished mimeographed paper, Ypsilanti, Michigan, 1949), p. 2.

[2]Glover, p. 37 quoting from Illinois, Proceedings of the State Board of Education, June, 1875, p. 13.

[3]Kuslan, "Science in Selected Normal Schools of the 19th Century," p. 460.

[4]Ibid., p. 475.

The University of California in Berkeley announced in the Catalogue of 1876-77 their plan of teaching zoology. It is not made clear according to the definitions used in this study that the laboratory method of teaching was utilized, but it is clear that it was not strictly taught by the lecture-demonstration method. Reference is made to the microscope. Hollister quoted the 1876-77 catalogue:

> "The course of lectures in this department will commence, in the junior year, with Zoology. It will include the comparative anatomy and physiology of animals and the principles of classification, and will be illustrated by a full set of diagrams, by the free use of the microscope and, wherever possible, by dissections.[1]

By 1876, Bessey had seven compound microscopes in use at the Iowa State University.[2] Thus, the lecture demonstration method had evolved into the analytical-objective method. In July, 1881, Bessey went to the University of Minnesota to teach a course of botany. This was the first time a botany course was "practically taught." As the University of Minnesota possessed no microscopes at that time, Bessey borrowed some from Iowa State College to teach botany at Minnesota.[3]

Bessey began teaching at the University of Nebraska in 1884. As would be expected from his methods of teaching at Iowa and Minnesota, he initiated work with the microscope there too. Pool quoted from the University of Nebraska Catalogue of 1884-85 about the botany course:

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[1] Hollister, p. 85.

[2] Pool, p. 237.

[3] Raymond J. Pool, "A Brief Sketch of the Life and Work of Charles Edwin Bessey," American Journal of Botany, II (December, 1915), 511.

> "Throughout the course the student makes investigations in the laboratory and field. The laboratory has a good outfit of working apparatus, including six new microscopes lately purchased."[1]

A type of laboratory teaching was introduced into the state normal school at Providence, Rhode Island, in 1880, when Alpheus Packard (1839-1905), of Brown University and a former student of Louis Agassiz (1807-1873), taught a series of lessons for the senior and middle classes at the Brown University. The teacher at Providence studied advanced zoology under Packard, and then she prepared charts for "types" study, purchased dissecting equipment, a few microscopes, and slides. According to the principal's report, there was a "rare collection of microscopic specimens . . . serviceable for class instruction."[2] Throughout the 1880's, "the first twenty-four of the fifty class meetings were devoted to the invertebrates and of course to the microscope."[3]

During the 1890's, some colleges were purchasing several microscopes at a time to aid in teaching. A general biology course was first offered at Knox College in 1895. As there was no money available for a laboratory, the three available microscopes were utilized the best way possible. The one good microscope belonged to the professor of astronomy and physics. There were 165 students in the course.[4] The

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[1]Pool, "The Evolution and Differentiation of Laboratory Teaching in the Botanical Sciences," p. 239.

[2]Kuslan, "Science in Selected Normal Schools of the 19th Century," footnote 2, p. 506, quoting "Report of J. C. Greenough, Principal of the Normal School," Annual Report of the Rhode Island Commissioner of Public Schools, 1881, p. 65.

[3]Ibid., p. 507.

[4]James G. Needham, "How Biology Came to Knox College," The Scientific Monthly, LX (May, 1945), 371.

faculty at the New Haven Normal School in Connecticut were utilizing the analytical-objective method of teaching during the last decade of the century. In 1896, five microscopes were received making a grand total of six at that institution. After that, continual requisitions were sent in to the central office for microscope slides, dissecting microscopes, stains, etc.[1]

It can now be seen that many colleges were going through a transitory phase between teaching by the lecture method and the use of the laboratory. The trend to purchase several microscopes, but not to adapt wholly the laboratory method, can be seen after 1870, to the end of the nineteenth century. Many of the schools which adopted this analytical-objective method of teaching were the normal schools. This would be expected for two reasons. First, the state-supported normal schools had little money and probably could not afford to buy a complete set of microscopes to outfit a laboratory. Second, as the normal schools were the most familiar with the object method of teaching children, it would seem only right that they adapt this method of teaching their own students; by practicing this method the student would learn it, and their meager supply of equipment could be used to its fullest potential.

The Laboratory Method of Teaching

It is commonly believed that the laboratory method of teaching was not introduced into the United States until after 1870. However it was first introduced much earlier when the unique, progressive Rensselaer

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[1]Kuslan, "Science in Selected Normal Schools of the 19th Century," p. 465.

Polytechnic Institute was founded in 1824. The entire program for the institution was educationally experimental in nature because the courses were taught mostly by laboratory work. A similar institution seemingly had not been previously established in either Europe or the United States. Quite possibly the founders of Rensselaer had been influenced by methods employed by some educators in Switzerland and France. However, their work had been in schools on the primary level. Samuel Blatchford (n.d.), President of the Board of Trustees, wrote in 1826: "The Rensselaerean scheme for communicating knowledge had never been attempted on either continent until it was instituted at this school some years ago. Many, indeed, mistock it, at first, for Fellenberg's method. . . ."[1] Apparently this was the first school involved with higher education to incorporate these new experimental methods of teaching on a full scale. In addition, according to Baker, Rensselaer Institute was the earliest institution devoted exclusively to science in any English speaking country.[2]

When Amos Eaton (1776-1842), at the age of forty-nine, was appointed head of the Faculty of Rensselaer School in 1824, he introduced the original method of instruction which was outlined in the early catalogues and circulars of the school. In a letter dated November 5, 1824, Van Rensselaer stated: "These (the students) are not to be taught by seeing experiments and hearing lectures according to the usual method,

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[1]Ricketts, p. 11.

[2]Ray Palmer Baker, "Rensselaer Polytechnic Institute and the Beginnings of Science in the United States," The Scientific Monthly, XIX (October, 1924), 337.

but they are to lecture and experiment by turns, under the immediate direction of a professor or a competent assistant."[1] Therefore, those who planned the program at Rensselaer scheduled for the morning of each day an extemporaneous lecture by each student on the subject of his course. The lecture was to be given from concise written memoranda. The afternoon was to be spent in "scholastic amusements" which was either laboratory work or field work, whereas the evenings were devoted to lectures delivered by the professors.[2]

Microscopes were considered as tools to be used in teaching from the time of the foundation of this institution. In a circular dated September 14, 1826, the description of the "scholastic amusements" to be pursued in the study of geography and history during the summer session included the use of the microscope. Specimens were to be selected for illustrating the physiology of vegetation. The specimens were to be examined under the common and the solar microscopes and drawings of their internal structures were to be made.[3] However, not one microscope is listed on the inventory of the equipment owned when classes started in 1826. By 1831, considerable additions had been made to the apparatus. "The philosophy room now contained an air-pump, a force pump, barometer, thermometer, pluviometer, solar microscope, megascope, standing microscope, magic lattern, telescope, etc."[4] With both the new method of

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[1]Ricketts, p. 17.

[2]Palmar C. Ricketts, History of Rensselaer Polytechnic Institute, 1824-1914 (2nd ed.; New York: John Wiley and Sons, 1914), p. 54.

[3]Ibid.

[4]Ibid., pp. 65-66.

teaching by doing in the laboratories and also the availability of microscopes, the microscope was probably used as a tool in the study of biology at this early date.

Unfortunately this method of teaching was isolated to Rensselaer Institute. It did not spread to the other colleges and institutions at this early date probably because of the educational philosophy of the time and the status of research in this country. When laboratory teaching was reintroduced into this country, it came from foreign influences; first, Agassiz from France introduced this method of teaching, but again it was not adopted by other institutions; second, the German influence in the 1870's finally provided the impetus for laboratory teaching. The microscope seemed to be readily adapted as a necessary tool in the laboratory.

Louis Agassiz accepted the chair of natural history at Lawrence Scientific School in 1848. He opened a rough laboratory and museum in an old boat house on the banks of the Charles River in Cambridge. His special students who were training to be naturalists worked on their own problems under Agassiz's stimulating criticism but with neither detailed directions nor instructional supervision.[1] According to Teller, Agassiz used a true inductive approach with his special students as they had to observe, compare, and generalize for themselves.[2] It would seem very probable that the microscope was utilized by these special students to do detailed, observational work, but this hypothesis could not be documented with references from the available literature.

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[1]Downing, p. 22. [2]Teller, p. 72.

Chittenden stated that regular laboratory work began in botany and zoology in 1869, at the Sheffield School. In comparative anatomy and embryology there was opportunity for work with something besides systematic description which characterized zoology and botany. There were dissections of various types of animals, and there was microscopical study of tissues which taught the methods of anatomical and histological investigation.[1]

An early laboratory was the one created for practical work in chemistry and pharmacy at the Philadelphia College of Pharmacy, founded in 1821, by the Alumni Association, in 1870. A picture of this laboratory taken in 1870, shows microscopes prominently displayed. Although it cannot be determined from the picture alone if microscopes were actually used, it seems probable that if they were available they were probably used.[2]

Another early use of the laboratory was begun in 1868, at the Massachusetts Institute of Technology when physics was taught in this manner.[3] Edward Pickering (1846-1919) wrote Elements of Physical Manipulation, a physics textbook based on the way he taught physics at that school. A description of his method is given below:

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[1]Russell H. Chittenden, History of the Sheffield Scientific School of Yale University 1846-1922 (New Haven: Yale University Press, 1928), p. 426.

[2]Joseph W. England (ed.), The First Century of the Philadelphia College of Pharmacy, 1821-1921 (Philadelphia: Philadelphia College of Pharmacy and Science, 1922), p. 162.

[3]Edward Danforth Eddy, Jr., Colleges for Our Land and Time (New York: Harper and Brothers, 1957), p. 74.

> Method of conducting a physical laboratory for which this book is especially designed, and which has been in daily use with entire success at the Institute, is as follows. Each experiment is assigned to a table, on which the necessary apparatus is kept and where it is always used. A board called an indicator is hung on the wall of the room and carries two sets of cards opposite each other, one bearing the names of the experiments, the other those of the students. When the class enters the laboratory, each member goes to the indicator, sees what experiment is assigned to him, then to the proper table where he finds the instruments required, and by the aid of the book performs the experiment. Any additional directions needed are written on a card also placed on the table. As soon as the experiment is completed, he reports the results to the instructor, who furnished him with a piece of paper divided into squares if a curve is to be constructed, or with a blank to be filled out, when single measurements only have been taken. In either case a blank form is supplied as a copy. New work is then assigned to him by merely moving his card opposite any unoccupied experiment. By following this plan an instructor can readily superintend classes of about twenty at a time, and is free to pass continually from one to another, answering questions and seeing that no mistakes are made. He can also select such experiments as are suited to the requirements or ability of each student, the order in which they are performed being of little importance, as the class is supposed to have previously attained a moderate familiarity with the general principles of physics. Moreover, the apparatus never being moved, the danger of injury or breakage is thus greatly lessened and much time is saved. To avoid delay, the number of experiments ready at any time should be greater than that of the students, and the easier ones should be gradually replaced by those of greater difficulty.[1]

Twenty-eight experiments were devoted to the section on light, five of which were on the microscope. Although Pickering advocated the use of only two or three microscopes, this was a sufficient number because of the rotating method described above. Pickering's section on the microscope and the names of the five experiments with this instrument are given below:

> Microscope. Apparatus. The importance of this instrument renders it desirable that each student should devote considerable time to

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[1]Edward C. Pickering, Elements of Physical Manipulation (Boston: Houghton, Mifflin and Company, 1873), pp. vi-vii.

its use. For this reason, in a large laboratory two or three microscopes should be procured, and it is well to have them from different makers, so that the student may be accustomed to all forms. For example, a "Student's Microscope," by Tolles or Zentmayer, to represent the American instrument, a binocular "Popular Microscope," by Beck, for the English, and a third instrument by Nachet or Hartnack, for the Continental form. The latter is very cheap and good, but not having the Microscopical Society's screw, common objectives cannot be used on it without an adapter. It is also well, if it can be afforeded, to have one first-class microscope stand for work of a higher nature. The usual appurtenances described below should be added, but not be duplicated, also a number of objectives and objects.

The following description will serve for all the common forms of instrument. A brass tube or body is attached to a heavy stand, so that it can be set at an angle, or moved up or down. In its lower end the objectives are screwed, and the eye-piece slide into the upper end. The objectives are made of three achromatic lenses, by which a short focus is attained, with great freedom from aberration. The eye-piece is of the form known as the negative eye-piece, and consists of two plano-convex lenses, with the plane surfaces turned upwards. Below is placed the stage, on which the object is laid and kept in place, either by a ledge, or by spring clips. In the larger stands the object may be moved by two racks and pinions in directions at right angles, or revolved by turning the stage. It is very desirable that this rotation should take place around the axis of the instrument, as is done in the English, but not in the American instrument mentioned above. Under the stage is the diaphragm, a plate of brass with a number of circular holes in it of different sizes, to admit light more or less obliquely. Below it is a mirror, plane on one side, and concave on the other, by which light may be reflected upon the object.

It is very important that the body of the instrument may be raised and lowered with precision. There are generally two adjustments to effect this, one the coarse adjustment to move it rapidly, which is commonly a rack and pinion, or a simple sliding motion effected by hand, and a fine adjustment which is used for getting the exact focus, and is made in a variety of ways. One of the best is by a movable nose-piece, or the lower end of the tube made free to slide, and acted on by a lever, which may be moved by a screw. In a second form, the screw acts directly on a part of the tube itself, and sometimes the stage is raised or lowered. If the tube is moved, it should be raised only by the screw, the lowering being effected by a spring, so as to prevent the objective from being pressed forcibly against the object. . . .

The first experiment deals with the ordinary method of using the microscope, the diaphragm, oblique illumination, opaque objects, the lieberkuhn, Wenham's Parabolic Condenser, achromatic condenser, polariscope, binocular microscope, Maltwood's Finder, micrometers, goniometers, camera Lucida (throws an enlargement of image on to paper for drawing), spectrum microscope, some test objects.

Experiment 80 Preparation of Objects. Instructions on how to prepare and view objects under the microscope is given. How to look at circulation of blood in foot of a frog.

Mounting Objects. Instruction for cutting into thin sections is also given.

Experiment 82. Foci and Aperture of Objectives.

Experiment 83. Testing Plane Surfaces.[1]

As was indicated above, summer schools were established to meet the need for instruction in the sciences. One of the earliest to make explicit mention of microscopical work was established by Louis Agassiz at Penikese, Rhode Island, on July 8, 1873. Around forty students who were mostly teachers in high schools and academies attended. In the morning, Agassiz lectured to the students upon the methods of studying natural history; the rest of the day was spent both in the laboratory followed in the evening lectured delivered by Agassiz. "Some students studied only a few forms of animal life, while others made their work of a general natural. Some devoted much time to the microscope and its revelations. . . ."[2]

In the summer of 1874, Harvard University established at Cambridge courses of instruction in chemistry and botany for teachers and others. Approximately thirty-five students, mostly teachers, were enrolled in the botany course. The instruction in botany consisted of work in the botanical laboratories with microscopes and dissecting needles and "innumerous lectures."[3]

In 1876, a summer school of biology, zoology and botany was established by the Peabody Academy of Sciences at Salem, Massachusetts.

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[1] Ibid., pp. 156-175.

[2] [Thwing], p. 503.

[3] Ibid., pp. 505-506.

Although it was intended primarily for the teachers of Essex County, the twenty students came from all over the East coast. In the opening address, Alpheus Packard stated: "We shall endeavor to study nature at first hand, and the scalpel, the pencil, and microscope will be the instruments of research."[1]

The third session of this summer school was announced in The American Naturalist as follows:

> Laboratory Work at the Seaside. The third session of the Summer School of Biology will be opened at the Museum of the Peabody Academy of Science, Salem, Mass., beginning July 5th and continuing six weeks. Lectures will be given five days of each week, and the best of opportunities afforded for laboratory work with the microscope. In addition to regular instruction in zoology by Dr. A. S. Packard and Messrs. C. S. Minot, J. H. Emerton and J. S. Kingsley, a series of afternoon lectures on microscopy will be given by Rev. E. C. Bolles. Admission fee, $20.00; board, $5.00 to $7.00 per week.[2]

Wellesley College was founded in 1875, as a college for women; it was to be "practically useful" and was planned "to meet the wants of American girls who intend to become teachers. . . . The main result which they desire to accomplish is to educate teachers worthy of the highest position; to instruct them by example and precept in the best modern methods of teaching. . . ."[3] Perhaps because of its objective, "to be practically useful," Wellesley placed great emphasis on laboratory work and special emphasis on microscopical work. In descriptions of courses at this institution it can be seen that the microscope was

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[1] Ibid., pp. 504-505.

[2] R. H. Ward (ed.), "Microscopy," The American Naturalist, XII (1878), 260.

[3] [Henry Barnard], "Wellesley College-Notes of Repeated Visits," The American Journal of Education, XXX (1880), 167-168.

not only a tool but its importance was probably more recognized here than at any other school of the time. Physics was taught by one of Edward Pickering's former students, and he taught the laboratory as Pickering advocated. Barnard stated: "We believe that it [Wellesley] has done more than any other college to promote the study of microscopy and its practical applications. In the apparatus and equipment for instruction in this science we know of no college that can compare with Wellesley."[1]

Barnard described Wellesley's Microscopical Department as follows:

> The microscope is the great instrument of modern science, and, therefore, when the course of physics commenced, it was decided to give great prominence to microscopy. A large collection of microscopes was procured, and their practical use in botany, chemistry, mineralogy and biology was encouraged. A microscopical society was formed, and kept up with good enthusiasm. The results accomplished in three years are exceptional. The College has by far the largest collection of microscopes in the country. There are sixty-five in number. Its battery of objectives and collections of accessory apparatus and microscopical preparations are unequaled. The work done by the students is truly worthy of praise. We saw slides that had been prepared by the students in the course of their practice that would be a credit to accomplished specialists. Among these we remember specimens of double staining in botany, and some remarkable specimens in histology. Although the study of microscopy is not confined to physics, it has its origin and impulse there. All the students are taught the optical laws and the practical use of the microscope, while its application is extended to other studies.
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> The College has a very complete library of microscopical work; not only in pure microscopy, but in its application to botany, biology, and mineralogy. This library, among other books, contains the only complete edition in this country of the works of Ehrenberg. All the microscopical journals and most of the journals which relate to applied microscopy, are regularly received. Last year an exhibition was given by the microscopical society to which scientists from Boston and Cambridge were invited. The work of the society

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[1] Ibid., p. 192.

> was exhibited under fifty different microscopes, showing preparations and practical work in various sections of microscopy. It is a great credit to this young College for girls, that so much has been done, in this direction.[1]

In 1883, Whiting stated that the Microscopical Society at Wellesley had access to ninety microscopes from the various laboratories of the school.[2] The interest of this school in the microscope was unique.

A laboratory designed primarily for microscopical work was established at the University of Michigan before 1876. At that time the science courses were grouped together in the Polytechnic School. The botany course was a study of anatomy and physiology of plants with microscopic examination of plant tissues. To facilitate the teaching of this course, a microscopical laboratory was created. It was open all morning every day, and it was supplied with microscopes and other instruments.[3]

By 1877, Professor Bessey was conducting botany laboratories with microscopical work performed by each student. In a letter to W. J. Beal at Michigan State, he stated that each sophomore student supplied himself with a simple three-legged microscope which cost seventy-five cents and had a magnifying power of nine diameters. The junior students who took Physiological and Cryptological Botany spent one afternoon a week in the physiological laboratory. Each pupil was provided one

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[1] Ibid., pp. 177-178.

[2] Sarah F. Whiting, "College Microscopical Societies," Proceedings of The American Society of Microscopists (Indianapolis, Ind.: The American Society of Microscopists, 1883), p. 27.

[3] Charles Kendall Adams, Historical Sketch of the University of Michigan (Ann Arbor, Michigan: University of Michigan, 1876), pp. 31-33.

compound microscope, one good scalpel, one pair of fine forceps, needle points, and reagents. The microscopes were Beck's Economic Microscopes which cost thirty-five dollars each.[1]

During the 1880's, laboratories were added to many science departments, and, as before, microscopes were utilized in these laboratories. The Bridgewater State Normal School in Massachusetts presented in the Catalogue of 1885 the first description of laboratories at that school. Provisions for microscopes were made. As the change to emphasis on morphology and physiology in the teaching of botany had occurred in the early 1880's, the advanced course was almost entirely microscopic anatomy according to the 1882 catalogue.[2]

A School of Biology was established at the University of Pennsylvania in 1884. Although a Department of Natural History had existed from 1816 to 1827 and a Department of Natural Sciences had been established in 1856, they were very ineffective. With the establishment of the new biology school, the laboratory method was emphasized. "There were from the beginning three notable characteristics of the Biological Department; it was open to men and women alike, students learned through actual observation and experiment, using individual microscopes and living material, and it was much given to research."[3]

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[1]Bessey, p. 232 quoting from a letter to W. J. Beal from C. E. Bessey dated Dec. 31, 1877.

[2]Alice Maria Van de Voort, The Teaching of Science in Normal Schools and Teachers Colleges ("Teachers College, Columbia University: Contributions to Education," No. 287; New York City: Bureau of Publications, Teachers College, Columbia University, 1927), p. 12.

[3]Edward Potts Cheyney, History of the University of Pennsylvania 1740-1940 (Philadelphia: University of Pennsylvania Press, 1940), pp. 300-301.

By 1885, much attention was being given to the microscope in both the botany and also the zoology departments at Harvard. William Farlow (1844-1919), the professor of cryptogamic botany, stated in 1886, that the use of the compound microscope was taught in the elementary botany course.[1] In 1855, a course called Microscopical Anatomy was established to teach microscopic technique in the zoology department.[2]

According to the 1889 catalogue, the microscope was incorporated in the teaching of Structural and Systematic Zoology at Wake Forest College. The laboratory method with dissection and typical specimens of the main groups of animals were also used in the teaching of the course.[3] Also, in 1889, in the catalogue of the Normal School in Terre Haute, Indiana, it was stated that there were thirty compound microscopes (twelve Leitz, twelve Beck's, and six Bausch and Lomb) and a dozen dissecting microscopes available for the teaching of the biological sciences.[4]

The incorporation of microscopes into the teaching of the sciences by the laboratory method has been reviewed. When laboratories were utilized to teach science, the microscope was adopted as an important tool. When Rensselaer Institute was established in 1824, the laboratory method of teaching prevailed, and the microscope was utilized within several years of the founding. Laboratory teaching was not

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[1]William G. Farlow, "Biological Teaching in Colleges," The Popular Science Monthly, XXVII (March, 1886), 579. Farlow had taught at Harvard since 1879, so it was possible that the use of the compound microscope had been taught from that date.

[2]Mark, p. 383.

[3]Cathcart, p. 51.

[4]Glover, p. 156.

introduced into another school until after the middle of the century when Louis Agassiz utilized this method to teach his special students at the Lawrence Scientific School. Although the microscope was used as a tool when laboratories were established throughout the 1860's and 1870's, special emphasis on the microscope and microscopic technique was first emphasized at Wellesley in 1875, and at other schools during the 1880's.

Summary

The role of the microscope in American colleges had been reviewed in this chapter. The advent of the microscopes into American colleges since 1734, and throughout the eighteenth century was noted. It seems probable that these microscopes were used to illustrate the lectures covering optical subjects in the Natural Philosophy Courses.

The educational philosophies, the state of biological research and teaching in the United States, the founding of special scientific schools and courses, and the normal schools and object training were discussed to define the backgrounds for the use of the microscope. As the philosophies of mental discipline and faculty psychology flourished in the liberal arts colleges throughout most of the nineteenth century, the curricula were primarily composed of ancient languages and mathematic courses. The use of the microscope would not be expected in these colleges until the elective system appeared and scientific courses were made a part of the curricula. As biological research seemed to be primarily taxonomical and descriptive throughout the first two-thirds of the nineteenth century and as biological teaching reflected this pattern

of research, it might be expected that the microscope would not need to be utilized to teach these courses; whereas, when the emphasis turned to morphological and cellular research and teaching in the 1870's, it would be expected that the microscope could play a vital role in the teaching of these subjects. Independent scientific schools, parallel scientific courses, and summer science schools were established throughout the nineteenth century to meet the need for science instruction; it would be expected that the microscope would be utilized in these institutions. The normal schools of the period were also quite practically minded and scientifically oriented. The method of teaching which prevailed in these schools, the object method, also would seem to encourage the use of any available equipment.

The use of the microscope was surveyed according to its use in three different capacities: (1) the lecture-demonstration method of teaching in which the professor would utilize the microscope to demonstrate his lectures; (2) the analytical-objective method in which some of the students also took part in the demonstrations; this would entail more student participation than the first method, but it would not be individual work as in the laboratory method; and (3) the laboratory method in which each individual student was able to participate in the work.

Table II, Use of the Microscope in American Colleges, summarizes the findings. The use of the microscope to demonstrate lectures occurred throughout the nineteenth century. In the liberal arts colleges, it was used to demonstrate the natural philosophy courses early in the century, and after the elective system prevailed, it was used to demonstrate

TABLE II

USE OF THE MICROSCOPE IN AMERICAN COLLEGES

Name of College	Lecture-Demonstration	Analytical-Objective	Laboratory	
			Other	Micro-Technique
Liberal Arts Colleges:				
Princeton (17th Century)	Nat'l.Phil. 1800			
Transylvania Univ.(1791)	Nat'l.Phil. 1805			
Kentucky Female Eclectic Institute(1831)	Nat'l.Phil. 1831			
Harvard (17th Century)	Botany 1844?	Zool. 1871-72	Bot. 1885	1885
			Zool. 1885	1885
Rochester Collegiate Institute	Nat'l.Hist. 1848			
Columbia Female Institute	? 1849			
Univ. of North Carolina	Zool. 1885			
Univ. of California, Berkeley		Zool. 1876-77		
Univ. of Minnesota		Botany 1881		
Univ. of Nebraska		Botany 1884-85		
Knox College		Biol. 1895		
Univ. of Pennsylvania			Biol. 1884	
Wake Forest			Zool. 1889	
Independent Scientific Schools and Land Grant Colleges:				
Iowa State College	Bot. 1871	Botany 1876	Bot. 1877	
Rensselaer Polytechnic Institute (1824)			Bot. 1831	
Massachusetts Institute of Technology (1865)			Physics 1868	

TABLE II--Continued

Name of College	Lecture-Demonstration	Analytical Objective	Laboratory: Other	Laboratory: Micro-Technique
Scientific Courses Affiliated with Liberal Arts Schools:				
Lawrence Harvard (1847	Botany 1856 Histology 1861 Zool. to Gen. Stud. 1868			
Illinois Industrial Illinois U.	Botany 1871			
Sheffield Yale (1847)			Bot. 1869 Zool. 1869	
Univ. of Mich. Polytechnic School				1876
Summer Schools:				
Peabody Academy of Science (1869)	Micr. 1868		Bot. 1876 Zool. 1876	
Penikese (1873)			Bot. 1873 Zool. 1873	
Harvard Summer School (1874)			Bot. 1874	
Colleges Established to Train Teachers and Normal Schools:				
Each Normal School in Massachusetts--1 microscope	1855			
Oswego (1867)	1867		Bot. 1876 Zool. 1876	
Forbes, Illinois	Biol. 1873			
Peru, Nebraska (1867)	? 1885			

TABLE II--Continued

Name of School	Lecture-Demonstration	Analytical-Objective	Laboratory: Other	Laboratory: Micro-Technique
Colleges Established to Train Teachers and Normal Schools: (Continued)				
Michigan State Normal (1849)		Bot. 1870's Zool. 1870's		
Illinois State Normal		Bot. 1875 Zool. 1875		
New Haven Normal		? 1896		
Wellesley College			Physics 1875	1875
Bridgewater State Normal			? 1885	
Terre Haute Normal School			? 1889	
Academies:				
Leicester Academy	Nat'l.Phil. 1798			
Wethersfield Female Seminary	Nat'l.Phil. 1826			

biological lectures if the other two methods did not prevail. This method was adopted quite readily by the normal schools if the other two methods were not utilized. In some instances it appears the number of available microscopes may have dictated the method of science teaching used. At Iowa State, the lecture-demonstration method was utilized from 1871 until 1876, when a sufficient supply of microscopes was available to permit the teaching by the analytical-objective method. By 1877, every student was furnished a microscope, and a true laboratory system could be established.

The microscope was utilized with the analytical-objective method of teaching from 1870, throughout the remainder of the century. There is a definite impression that this method was utilized after the elective system was initiated in the liberal arts schools but before a sufficient supply of microscopes were available for a true laboratory method of teaching. This hypothesis seems probable as this method was utilized most in both the liberal art schools and also the normal schools where equipment was not abundant.

Contrary to popular belief, laboratory teaching had been introduced into American higher education many years before Huxley introduced it in England, and it was employed in several institutions several years before that time. The microscope was seemingly utilized whenever the laboratory method was introduced. The laboratory method and the microscope were introduced earlier and were more prevalent in the scientific institutions, courses, land-grant colleges, summer schools, and normal schools than in the liberal arts colleges. The microscope was employed with the laboratory method as early as 1831 at Rensselaer Institute and in the 1860's and 1870's in other schools. Special emphasis

on the microscope itself and microtechnique was initiated at Wellesley as early as 1875, and at the University of Michigan Polytechnic School in 1876.

The microscope was an accepted tool by 1890, as can be seen by a survey conducted by Campbell on biological teaching. The survey was sent to all colleges who had more than fifty students and to all the scientific schools. One hundred eighteen schools returned detailed descriptions of their biological departments: ninety-one mentioned laboratory work, seventy mentioned the availability of microscopes; fifteen mentioned work in microscopy--either separate courses or a distinct part of another course.[1]

It can be seen, then, that the microscope was used as a tool to teach science throughout the nineteenth century. Its relatively late use in the liberal arts colleges was probably due to the educational philosophy of the time, and its rather limited use in the other institutions before 1870, was probably due to the state of biological research in this country during the nineteenth century.

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[1]John P. Campbell, Biological Teaching in the Colleges of the United States ("Bureau of Education Circular of Information," No. 9; Washington: Government Printing Office, 1891), passim.

CHAPTER VII

CONCLUSIONS

The microscope has been available in one form or another since around 1600, and it grew in popularity as a means to investigate nature throughout the seventeenth and eighteenth centuries. Particularly during the eighteenth century, the instrument enjoyed great popularity and much general attention was given to it. Investigators of biological phenomena began to utilize it and new areas of study were developed because of its utilization.

Yet, it is generally known that the microscope was not part of classroom equipment until the latter part of the nineteenth century. Reasons why the adoption of this instrument by educators occurred later than an acceptance of this tool became the motivation for the present study. The purpose of this study, then, was to survey the evolving use of the microscope as a tool in science education and to relate this increasing use of the microscope to the changing methods of teaching scientific courses, to the changing content and emphases of the scientific courses, and to the prevailing philosophies of education.

This study was limited by several factors. First, it has been limited primarily to the nineteenth century although the advent of the microscope into educational institutions during the eighteenth century

was reviewed to provide the necessary background for its use in the nineteenth century. Second, the study has been concerned only with higher education. Many different facets of higher education have been included, though, such as the medical schools, the independent scientific schools, the parallel science courses, the summer science schools, and the normal schools. Third, the primary area of interest has been the investigation of the use of microscopes in American colleges. Because American education was greatly influenced by European education, one chapter was devoted to the examination of the role of the microscope in institutions of higher education in Germany, England, and France.

To accomplish the purposes of this study, it was necessary to establish background information which was needed to clarify the evolving use of the microscope. First, it was necessary to review the evolution of the microscope. It was found that microscopes were probably developed independently by both Galileo in Italy and the Jansens of Holland between 1590 and 1620. The development of both the single and also the compound microscopes throughout the following years was reviewed. It was also concluded that achromatic lenses were probably first utilized successfully in microscopes by Benjamin Martin around 1774, and by Francois Bieldonyder around 1791. Achromatic microscopes were being commercially manufactured and were available from the 1820's. Microscopes were continually improved throughout the nineteenth century. Although the term "the microscope" was used throughout this paper, it was not meant to imply that only one type of microscope was used. The microscope continued to evolve throughout the nineteenth century as it did during the seventeenth and eighteenth centuries.

The availability of microscopes during the nineteenth century both in the United States and abroad was also surveyed. It was found that microscopes were available from 1830, throughout the nineteenth century in Europe and that microscopes were being manufactured after 1850, in the United States. It became evident also that companies in Germany, France, England, and the United States developed and advertised special economical, but quality microscopes which were sold as student microscopes from the middle of the century. In America at least ten companies were selling twenty models of student microscopes in the early 1870's. These instruments were high quality compound microscopes which were selling from between fifty to one hundred dollars. Good, relatively inexpensive microscopes were available after 1850 in both the United States and in Europe.

As the educational philosophies and methods of instruction in American institutions of higher education were greatly influenced by the European practices, the role of the microscope in the foreign universities was examined. It was found that the microscope was used earlier and more widely by students in Germany than in England and France. As soon as the achromatic microscope became available in the late 1820's, it was used by students in the small private laboratories of the professors who were also scientists. The microscope was also apparently used throughout the century both to demonstrate lectures and to provide student experiences in the laboratories in German institutions. It was hypothesized that several conditions which existed made this early use possible; a strong state-centered and state-administered educational system made possible the type of research-oriented university which

existed in Germany during the nineteenth century and the subject matter of this scientific research, morphological research, which utilized the microscope was prevalent in Germany during the early part of the nineteenth century.

The educational system in England was characterized by a lack of state organization and direction and a strong social rather than intellectual tradition. The scientists in England were not, as a rule, the teachers in the university; the university and the scientific worlds were separate. This was reflected by the slow adoption of the microscope as a tool in the teaching of science in English universities. It was found that the major universities, Oxford and Cambridge, owned microscopes in the eighteenth century, but seemingly they were not used to demonstrate specimens in science-oriented courses until the fifth decade of the nineteenth century, and, then, their use seemed to be sporadic. Noticeably lacking were references to individual work with microscopes by students in the professors' private laboratories which characterized German science education. There was some use of the microscope before the 1870's when Huxley introduced the laboratory method, but its use probably gained importance with the introduction of this method of teaching.

France had a national system of education, but the scientific life remained largely free of the universities. As scientific research was not seemingly carried on in the universities, the utilization of the microscope in teaching was slow as in England. References to use of the microscope occurred first around the middle of the century. As in

England, work by students in professors' private laboratories evidently did not occur in the early nineteenth century.

The role of the microscope in American medical schools was examined next. It would seem that the subjects which are taught in medical schools would prompt an early use of the microscope in illustrating the lectures at least. However, it was found that the general use of the microscope by the American medical schools was quite retarded if not neglected during the nineteenth century. A review of the history of the medical schools of that period revealed the probably cause for this situation. The medical schools were, on the whole, commercial establishments which were independent of any scholastic institution. Even schools which carried the name of colleges were mostly proprietary schools. They consisted of a two-year ungraded course which was primarily didactic. Local medical doctors owned the medical schools and received their "salaries" directly from student fees. Secondary education was not even a prerequisite in the majority of these commercial schools at the end of the nineteenth century.

There was some student use of the microscope in a few of the medical schools. In the 1840's, the microscope was utilized by some of the country medical schools to teach microscopical anatomy, but these were exceptional institutions. Some extramural courses were taught to meet this need. Around and after 1870, a few more medical schools began demonstrating with the microscope and even began teaching the students the use of the microscope. However, it was estimated that students in less than ten percent of the medical schools in 1890, were receiving the opportunity to learn to use and to work with the microscope.

The advent of microscopes into American colleges during the eighteenth century was reviewed. It was found that microscopes either had been given to or bought by several colleges since 1734. It was concluded that these microscopes were probably used to illustrate lectures on optics during the Natural Philosophy courses. The microscope was probably looked upon as a scientific phenomenon rather than a tool to study natural phenomena.

To understand the evolving use of the microscope, some necessary background had to be established. The fact that the concepts of mental discipline and faculty psychology were the dominant educational philosophies of the nineteenth century explained the reason a set curriculum of ancient languages and mathematics existed in the liberal art colleges during the first three-quarters of the nineteenth century. This set curriculum allowed little opportunity for the inclusion of the biological sciences which were developing.

Also during this period, biological research in the United States was still in the taxonomy-natural history stage. Even when some biologically-oriented subjects were taught, this type of subject matter was stressed, and consequently there was little need for the microscope to help teach.

As science courses were not taught in the liberal arts colleges, special schools and courses were established to meet the need for scientific instruction in this country. Some separate scientific institutions such as Rensselaer Polytechnic Institute, established in 1826, were designed to teach scientific and technological courses by the laboratory method of teaching. Separate scientific schools were established

alongside some of the traditional colleges such as Lawrence by Harvard in 1847, and Sheffield by Yale also in 1847. The land grant colleges were created by the Morrill Act of 1862, and although their effect on colleges and universities was evident later in the nineteenth century, their recognition of scientific and technical courses as part of the legitimate curricula was influential. Around 1870, summer science schools were established to teach science.

The normal schools which were established after 1839 to train teachers for the public schools placed great value on scientific studies. As these schools were utilitarian in spirit and as the educators in the normal schools believed that the teaching of science deepened an appreciation of God, it was natural that the scientific subjects would be emphasized. Also the object method of teaching was being taught by the normal schools during the last half of the nineteenth century. This method of teaching encouraged the use of available equipment including the microscope.

To analyze the increasing use of the microscope, the adoption of it as a tool to teach science was classified according to the methods of science teaching: (1) the lecture-demonstration method, (2) the analytical objective method which encouraged more student participation than the first method but less than the third, and (3) the laboratory method of teaching.

The results of this analysis were quite interesting. First, it was found that the microscope was used to demonstrate lectures throughout the nineteenth century. However, it was utilized for these demonstrations during the first three-quarters of the century mainly by the

special scientific schools and courses. It was not until after 1870, when the elective system was finally adopted and the German universities were exerting an influence on the American colleges that the microscope was utilized in the liberal arts colleges.

Second, the microscope was used in the analytical-objective method of teaching after 1870. It was utilized primarily by the normal schools who had limited equipment and who would adopt this method of teaching as it was an "adult-object" method. Some of the liberal arts colleges also utilized this method probably because of a limited supply of equipment.

Third, when laboratory teaching was introduced into an institution, it seems that the microscope was readily adopted as a tool in the laboratory. It was utilized in 1831, by Rensselaer Polytechnic Institute, which was the first institution to introduce the laboratory method of teaching into American higher education. After 1870, when laboratory teaching was accepted in many colleges, the microscope was also incorporated. Special emphasis was given to the microscope and microtechnique by Wellesley College from the time of its establishment in 1875. The School was founded primarily to train teachers. Other schools began teaching special microscopical courses after this date.

In conclusion, it can be stated:

1. Microscopes were probably developed independently by Galileo and the Jansens in the early seventeenth century.

2. The achromatic microscope was developed for and in production by the 1820's.

3. Relatively low priced, high quality student microscopes were readily available both in Europe and in the United States after 1850.

4. The microscope was utilized in the teaching of students after 1820, in German institutions in the private laboratories of the professor-scientists and then in the classroom.

5. The English and French were comparatively slow in adopting it; not until the latter part of the nineteenth century was it adopted.

6. Because the commercial medical schools abounded in America, the microscope was utilized in the American medical schools rarely before 1870, and in only a few of the better schools after that date.

7. The microscope was utilized for demonstrations of lectures throughout the nineteenth century although the laboratory method of teaching did not prevail until 1870.

8. Before 1870, it was used primarily by the special science schools, the separate science courses, and the normal schools who stressed teaching of science courses.

9. It was not generally used by the liberal art colleges until after 1870, when the elective system was successfully introduced and the German ideas of higher education were accepted.

10. Schools whose objectives included the training of teachers, such as Rensselaer Polytechnic Institute, Wellesley, and the normal schools utilized the microscope when it was available from the time of their establishment.

11. The microscope and microtechnique was emphasized at Wellesley from the time of its establishment in 1875; other schools consequently began teaching microtechnique.

Recommendations for other studies can be made from the results of this present study. A great need exists for the study of many facets of the history of science education. The writing of such histories should be done by historians of education and historians of science.

Now that a broad survey of the trends in the use of the microscope has been made in this study, the use of the microscope in individual institutions could be investigated. For this, local records, professors' outlines of courses, laboratory guides, and students' notebooks should be perused.

The study of the adoption of other equipment in the teaching of science would also be interesting problems. The development and the utilization of the kymograph is one intriguing possibility.

The history of the summer science schools established after 1860 would be a challenging study. It is not believed these were the summer "Chautauquas" established by Sheldon, the founder of the Oswego Normal School. In the extensive search of the literature for the present study, the only references to these summer schools were made in the literature of the late 1860's and the 1870's. From the notices which appeared in the periodicals of that time, it can be ascertained that these schools were taught mainly by the laboratory method and were taught primarily for teachers. However, few references to these schools could be found in recent literature.

Many possibilities exist for the study of the history of science education; it is a relatively unexplored field and a phase of education that is often neglected by historians of colleges and universities even though the establishment of each fraternity is recorded with care. An understanding of how science has been taught might help provide an explanation of the Americans interpretation of science.

APPENDIX

THE MICROSCOPES AND SLIDES AT TRANSYLVANIA

The objects to be examined by the Lucernal microscope are illuminated by the light of a lamp or a candle. In our instrument the arm for the lamp is in place but the lamp is missing. With this particular instrument there was purchased a large collection of natural history objects--plant, animal, and mineral. Some of these objects are for transmitted light and some are in wooden troughs for reflected light.

The following direction (in part) came with the microscope: "First light the Lamp with the best oil and cotton for a steady and good light. Then slide the microscope firmly on its case. Slide out the small wood slider at the top end of the microscope cone, and push up the Shutter. Screw on at the large end the sliding brass tube to which fasten the sliding sight piece. Slip on the stage bar the two condensing lenses, the smallest one first. For opake objects place the ebony slider at the spring stage. Your face before the large condensing lenses and the roughed glass taken out, place the lamp on the left side of the microscope the flame being at the height of the object. Place the jointed adjusting handle at the right hand pinion and the plain one through the ring at the left hand side of the cone to the opposite square.

"A beginner should use No. 6 magnifyer, an object being placed directly opposite to the magnifyer, move the light and condensing lenses so that the light may be fully and strongly condensed on the object. Now place your eye to the hole of the sight piece opposite to the centre of the large lenses and move the tube of the magnifyer until the objects appear nearly distinct, then with your eye at the sight hole turn gently the stage adjusting rod until the objects appear nearly distinct, then with your eye at the sight hole turn gently the stage adjusting rod until the object appear the most distinct and best defined possible. The effect will be very brilliant and striking. The roughed glass being placed before the lenses, will receive the images of the objects on its surface and will anable a person to copy their outlines with a pencil."

The following is from a 3 x 6-1/4 inch, hand-made, blue covered 20 page booklet of paper water-marked "1838." It was found in the tray of this microscope. Practically all of the

specimens described are still extant and in fairly good condition. The date of the booklet gives some indication of the original purchase date of the Fall collection.

(Title page) Liste/ of/ Transparent/ and Opake/ Objects/ for the/ Improved/ Lucernal/ Microscope/ by/ W. and S. Jones/ 1839

(Page 2) Transparent objects in the six small Ivory Sliders. No. 1. Hair of a Mouse, Ditto of a Bat, Down of a Tussock Moth, Do of the Noctua Nupta. No. 2. Tongue of a Bee, Sting of a Ditto, Claw of a Ditto, Wing of a Wasp. No. 3. Eyes of a Spider, Jaws of a Ditto, Leg of Ditto, Wings of Cicada.

(Page 3) No. 4. Tongue of a Butterfly, Eye of a Ditto, Antena of a Moth, Legs of Ichneumon fly. No. 5. Tongue of the house fly, Eye of a Ditto, Farina of Holly Hock, Wing of a Cricket. No. 6. Scale of a solefish, Ditto of a Dace, Seed Vessel of Sorrel, Field Spider.

(Page 4) Transparent Objects, Sections of Wood in the 6 large Ivory Sliders. No. 1. Cane, Dwarf Almony, Aucuba, Sycamore. No. 2. Broom, Yellow Jessimin, Pyrun Japonica, Peach. No. 3. Willow Root, Willow Branch, Snow Ball or Guelder Rose, Spanish Chestnut.

(Page 5) No. 4. Bay Tree, Cedar Tree, Clove, Hypericum. No. 5. Gum Cistus, Buckthorn, S. American Rush, Nectarine. No. 6. Pear tree, Sumach, Raspberry, Mountain Ash.

(Page 6) Transparent Objects in the 3 large Boxwood Sliders. No. 1. Skin of a Spider, Ditto of a Snake, Legs of a Dragon fly, Dissected leaf, Wings of a bee. No. 2. Bloom of Grass, Wing of Grasshopper, Do of Ichneumon fly, Do of the Currant moth. Do of the Ephemera.

(Page 7) No. 3. Wings of the Dragon fly, Ditto of Libellula, Do of the Hemerobius.

(Page 8) Opake Objects in the 18 Ebony Sliders. No. 1. Small English Insects, Bronze Carabus Bettle, Small Oak Circulios, Asparagus Beetles. No. 2. Gold Circulios, Green Chrysomela, Catharides, Spanish fly, Blue Chrysomela. No. 3. Cincindella Comprestis, Part of the wing case of Ditto, Corslet of Diamond Beetle, Wing of Buprestis Chineese Fly.

(Page 9) No. 4. Feather of a Turkey, Wing of a Butterfly, Wing of a Locust, Feather of a Peacock. No. 5. Mised Poppy Seed, Mignonette Seed, Carraway Seed, Parsley Seed. No. 6. Burnet Seed, Cornbottle Seed Thorapply Do, Sn. Fain Do. No. 7. Small English Shells, Variety of Ditto, Small Trochus, Nerita Verginia.

(Page 10) No. 8. Screw shell and Section, Nautilus Pyrula, Spotted Columbellas, Small Pecten. No. 9. Small Crab, Sea Echinus, Scales of Perch, Skin of Dog fish. No. 10. Red Coral, White Corralline, Gorgona Sea Weed, Madrepora.

(Page 11) No. 11. Dissected leaf, East India Pearls, Common Scotch pearls, Oolite or Roe Stone. No. 12. Crushed Minerals, Small Emeralds, Do Bargetts, Iron Sand. No. 13. Tinstone Ore, Gold Colored Mica, Lepidolite, Crystallized Bismuch.

(Page 12) No. 14. Galena, Sulphuret of lead, Green Phosphate of lead, White Caronate of Do, Sum of lead. No. 15. Cubical Iron Pyrites, Oxydulated Iron Ore, Mundic, Iron pyrites, Dpecular Iron Ore. No. 16. Orpiment, Native sulphur, Realgar Sulphuret of Arsenic, Cinnabar Sulphuret of Mercury, Steel grains Iron Ore.

(Page 13) No. 17. Malachite Green Carb of Copper, Red Oxide of Copper, Peacock Copper Ore, Native Copper. No. 18. Spicular Antimony, Lapis Laxuli Ultramarine, Silver Ore, Grains of Platina."

. . . . . .

A compound microscope known in its day as "Jones most improved" is a complete instrument with insect boxes, fish trough, auxiliary magnifiers, etc. It represents the peak of compound microscopes during the early nineteenth century. The microscope is now in only fair condition and the mirror is missing.

In the 34d Ed. of the Encyclopedia Brit., Vol. XI, p. 715, there is an article which shows that our Jones Most Improved Microscope had its start in an instrument first known as Martin's New Universal Compound Microscope. We also are told that a Mr. Jones of Holborn, London, suggested several alterations. The figure of this microscope as altered by Mr. Jones shows that it is still not as useful as the "most" improved model, which must, of course, have been a still later model. The third edition of the Britannica was published before the turn of the 19th century and our microscope was undoubtedly made several years later.

Microscope (Lime-light) This is the most complete of three cal-oxyhydrogen microscopes which were purchased by the early University. We still have a large collection of objects made to be viewed with the aid of this particular apparatus. The microscope illustrated was made by W. and S. Jones of London. The other two were made by E. M. Clarke, also of London, and by McAllister of Philadelphia. Perhaps an interesting feature of this instrument is the housing on top of the tripod in which was generated the lime-light. The tripod support stands about five feet tall and the housing measures 15 x 12 inches. The complete instrument with its objects for study were valued by Dr. Fall at $910.00.

Microscope (Cal-Oxyhydrogen "lime-light"). An early sketch showing the way in which the lime-light project was made ready for use. One of the bellows was filled with oxygen, the other with hydrogen. The pressure exerted by the weights was sufficient to force these gasses from the nozzles within the hood. Knifht's Dictionary (1877) describes the Oxyhydrogen Lamp as an improvement over the Oxycalcium light in these words, "one in which streams of oxygen and hydrogen in regulated quantities are commingled, the resulting flame being directed on a ball of quicklime and forming an extremely bright light; now used very largely by lecturers on science to illustrate phenomena, and by exhibitors to project pictures upon a screen."

Microscope Sliders. These are a few of the many objects in the Transylvania collection. Each specimen of plant or animal is

preserved in Canada Balsam between plates of glass and then these are put in hardwood frames. They then were used for projection by means of cal-oxyhydrogen microscope, which in reality was a type of magic lantern using "limelight."

There are twenty-three sliders with unvarnished wooden frames made with mitered corners. The outside dimensions of these measure 151 x 56 mm. The identifying legend is written on the frame in India ink. There is no name of the maker for this series.

The larger series of 72 sliders was made by W. and S. Jones, 30 Holborn, London. These are the sliders illustrated. The wooden frames, usually of varnished mahogany, measure 185 x 62 mm. The central openings which contain the specimen vary in size and shape depending on the size and shape of the specimen. Several (11) of the sliders have been crudely cut down in recent years, presumably for the purpose of projecting them in a modern micro-projector. The fate of these eleven sliders emphasizes the necessity of separating old from contemporary apparatus.[1]

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[1]Leland A. Brown, Early Philosophical Apparatus at Transylvania College (Lexington, Kentucky: Transylvania College Press, 1959), pp. 51-62.

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