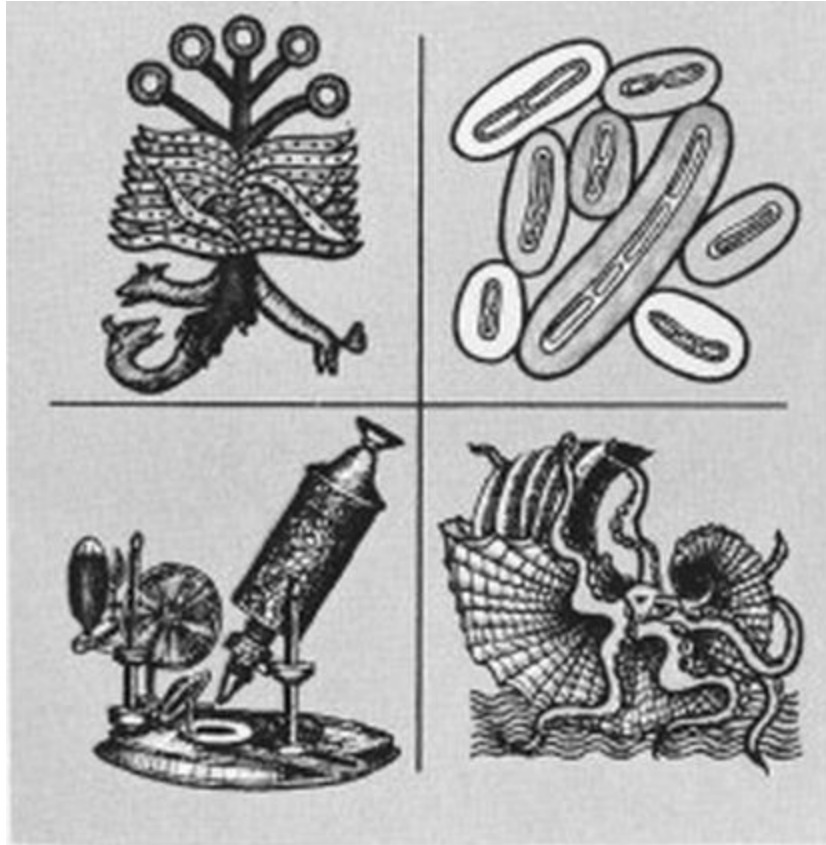


Developing a Course in the History of Biology



(Mallat, 1962)

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Table of Contents

Abstract.....	5
Acknowledgements.....	6
1. Introduction.....	7
• 1.1 Course Introduction.....	7
• 1.2 Course Design.....	7
• 1.3 Historical Context.....	8
• 1.4 Teaching Styles and Methods.....	9
• 1.5 Difficulties with Traditional Teachings.....	14
• 1.6 Student Psychology and Concept Maps.....	15
• 1.7 Prior Knowledge.....	15
• 1.8 Declarative and Procedural Prior Knowledge.....	16
• 1.9 Active Learning.....	17
• 2.0 Course Ramifications.....	18
2. Materials and Methods.....	21
• 2.1.1 Introduction of the Materials and Methods.....	21
• 2.1.2 Multiple Approaches to Topics.....	21
• 2.1.3 Original Documentation.....	22
• 2.1.4 Reinforcing Homework.....	22
• 2.1.5 Reflective Writing.....	22
• 2.1.6 Classroom Discussion.....	23
• 2.1.7 Concept Mapping.....	23
• 2.1.8 Elaborative Interrogation.....	23
• 2.1.9 Ongoing Assessment.....	24

- 2.2.1 Laboratory Design.....24
- 2.2.2 Assessment.....25
- 2.3.1 Microscopes and Magnification Lab Experimental Procedure.....29

3. Results.....30

- 3.1.1 Tentative Class Schedule and Units.....30
- 3.1.2 Concept Map.....31
- 3.1.4 Homework Assignments.....32
- 3.1.5 Microscopes & Magnification Prelab.....33
- 3.1.6 Laboratory Experimental Handouts.....34
- 3.1.7 Water Microscope Experimental Handout.....35
- 3.1.8 Creative Writing Assignment.....36
- 3.2.1 Van Leeuwenhoek’s Letters.....37
- 3.2.2 Hooke.....38

4. Discussion.....40

- 4.1 Overview of Course’s Design.....40
- 4.2 Microscopes & Magnification Unit.....42
- 4.3 Possible Course Alterations.....44
- 4.4 Unit Designs and Alternative Experiments.....44
- 4.5 Teaching and Learning Analysis.....46
- 4.6 Future work.....48

5. Conclusion.....50

6. References.....51

7. Appendix I.....	54
• I. IRB Application.....	54
• II. IRB Approval Letter.....	59
8. Appendix II.....	60
• I. Extra Materials for the <i>Microscopes & Magnification</i> Unit	
9. Appendix III.....	111
• I. Micrographia Interactive E book	
10. Appendix IV.....	113
• I. Materials for the Miller-Urey Experiment Unit	

Abstract

Studies in course design have indicated that it is much more efficient to implement an active learning environment for students. Participation through discussions and activities results in a greater intake of knowledge by the students. This course was designed to incorporate multidisciplinary skills in the classroom. The History of Biology integrates a scientific lab section with a history class. *Microscopes* is a sample unit in the course and incorporates scientific concepts and historical information. The lab section introduces the students to the lesson by having them use critical thinking skills in order to grasp important concepts prior to the lecture. Other project ideas have been included to show an approach to a different historical time period with modern scientific advancements.

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1. Introduction

1.1 Course Introduction

This Interactive Qualifying Project is intended for the design of a multidisciplinary course in biology and the history of biology, which will be conducted at Worcester Polytechnic Institute. This class will emphasize problem solving and independent learning, presenting students with a historical problem scientists faced in the past, and having them design a way to solve said problem. Ideally, students will not know the necessary background information from the experiment and will instead resort to critical thinking skills in order to design and run their own experiments. Students will be exclusively provided certain tools that would have only been present at a specific time in history. After the experiment, professors will present the historical background from that time period as well as the important scientists involved and their methods of problem-solving.

Worcester Polytechnic Institute strongly emphasizes the importance of group collaboration. This is not only possible while studying STEM topics, but this group collaboration can also be done in a cross-disciplinary manner. This would allow students to delve into numerous topics, while also examining subjects from a novel perspective. By creating a course that incorporates group work as well as multifaceted learning, students could potentially earn credit from multiple disciplines while also extracting important themes from those respective subjects.

1.2 Course Design

The class will be set up similar to a Great Problems Seminar (GPS) offered at WPI. The GPS is done to help introduce students to university level research and project work. The *History of Biology* course will mimic the Great Problems Seminar in the length of the class, one semester, as well as the qualities that it provides to students. The GPS offers many important

skills to be learned by the students that will help them effectively integrate into university based learning, research, and management. More specifically, it is the aim of the GPS courses to incorporate skill sets such as group work, research, writing, problem solving, presenting, interdisciplinary understanding, and sensitivity to various cultures and approaches (WPI, 2014). The *History of Biology* course aims to achieve these goals by designing a unique framework.

1.3 Historical Context

This course will be intended to instill in its students not only an understanding of science, but more importantly a sense of historical context in which biology was developed. Discoveries people tend to take for granted in present times, were often revolutionary and even controversial historically. For example, in 1912 Dr. Robert Goddard proposed several innovative concepts that would revise the way current rocketry was perceived in the scientific realm. Goddard's research was later published in 1914 and included several important findings regarding rocket efficiency (Goddard, 1920). His research resulted in criticism by scientists and the public because he worked in secrecy and lacked compliance in terms of collaboration. Many scientific discoveries have taken place through the span of history in which the scientists' working conditions, available resources, and societal pressures impacted the progress of discovery. We take the fact that all organisms are made up of cells, and that there is a microscopic world just out of sight as commonly known facts while neglecting to explore their origins and the historical context surrounding these discoveries. Because innovations often occur as a result of the environment and necessities of the people, it is imperative to account for the historical perspective in the course as well as the biological one to fully understand how research often occurs.

Let's trace one biological school of thought that is now obsolete. Ancient Greek philosopher Aristotle (384 BC-322 BC) contributed much to the world of philosophy, but he also contributed to the idea of spontaneous generation. (Lennox, 2006) He believed that heat was one of the sources of life and that grubs were born from dung, because they still retained some of the heat from the being that produced the dung. Since Aristotle was a well respected philosopher his

teachings remained influential and persisted into the 1700s. These notions led to the creation of the theory of spontaneous generation.

Spontaneous generation was a theory that life came from inanimate objects. For example, rodents may come from dry hay bales that are exposed to air. Although this may seem like foolishness to modern day scholars, this idea made sense to people at the time. After all, if you closed the hay off from the outside air the mice did not appear to show up in the hay. This theory continued through much of European history. (Paustian, 2012) Spontaneous generation is an example of a completely incorrect theory that seemed to make sense based on the apparent truths at that time in history.

Throughout the year, the team studied the historical context in which discoveries were made and theories are disproven. By looking at the social and political climate that shaped the way scientists perceived problems. The developed plan is to teach students about the current events at a specific time period and how these events impacted the scientists working on problems. In this, we shall paint a picture of how the circumstances affected their abilities and needs to do their experiments.

1.4 Teaching Styles and Methods

Pursuing a certain teaching style for the course is important as it may dictate the manner that the student learns. Particular guidelines need to be implemented in order to insure that the students gain both knowledge and valuable experience from the material. The course offers both a history and biology credit, something rarely done on most campuses as indicated by Charmany et. al. in their 2008 paper, and strives towards more efficient learning methods for the students. The inclusion of the History of Biology course would become an example of the benefits of active learning and more classes like this may be added to other universities.

It has been proved many times that lecture-based learning does not promote critical thinking skills or engage students to learn (Lake, 2001). Many college courses offered follow lecture based teaching methods that include difficult goals for the students to reach. These can include minimal time available to grasp important concepts taught during lecture. Students may have trouble retaining information and lack confidence in approaching problems encountered during a course as well as after it has ended (Fink, 2003). The goal of the *History of Biology* course is to offer the students a new method of learning; a hands on approach to encountering scientific problems. Because the course offers a lab where the students have to independently work through experiments and problems, they may understand solutions better as well as the importance of their struggles, mirroring the struggles of scientists over time.

Often, students do not understand the importance of scientific experiments and the impact they had on the advancement of science and technology. Usually, material presented in the form of hard facts and experiments is reduced to the results while glossing over the efforts men and women took to overcome obstacles and reach their findings (Fink, 2003) Allowing a student to experience such endeavors will most likely result in an increased appreciation for science leading to an equal increase in interest of the course as well as confidence in pursuing problems. Their gained confidence and problem solving skills can be applied in all aspects of life, not just the course they applied them in.

In order to create significant learning experiences, students must be exposed to different styles of teaching as well as connections of what they have learned to real life. Without these two, the knowledge they gain in the course may be easily forgotten. It is especially important to be able to form the bond between what they learned and how they can apply it. Proficiency in this will result in both the success of the course as well as what the student takes from the course (Fink, 2003).

The way in which the course is designed also has a great impact on its success. Changing the paradigm may sound simple, but there are many problems associated with that. The difficulties

in creating a learning environment that is both rich and enduring for the student are complex in nature. Since student needs are quite variable and independent, one particular teaching system may not be universal. Some of the common learning problems encountered with students are boredom, lack of class attendance, preparation prior to class time, and deficient retention of knowledge (Fink, 2003). Organizing the course to promote significant learning is vital, but will take time and effort to optimize. Assigning homework or pre-laboratory write-ups will help prepare students by providing a source to learn outside of the school. It will also help reinforce material from discussions and including these assignments is important in all classroom settings (Fink, 2003) This should lead to a buildup of confidence for the student and then possibly lead to their being more engaged with the material during class time. The lab portion of the *History of Biology* course influences the student to get prepared outside of class in order to move through the experimental portion quicker and with more ease. Including the lab section ensures that students try to prepare more thoroughly beforehand, as opposed to having only a lecture where students are more inclined to participate at a passive level. Along with this, the pre-lab assignments that are required will also help them process knowledge and gain creativity before beginning experimentation in the lab.

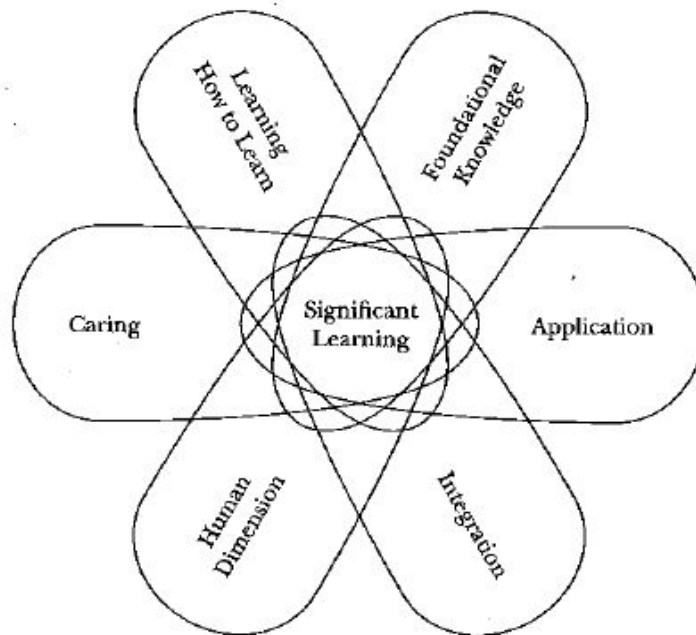


Figure 1: Dynamic Diagram of Interactive Learning (Fink, 2003)

Interactive learning is a dynamic process of multiple dimensions as shown in the diagram below. Students are all different in the way that they learn and often times multiple methods of teaching are required in order to make a positive impact. The first step is to set up specific course goals and then more general curriculum goals. Afterwards, creating the course outline and figuring out different ways to explain a topic is important. One of the most consequential parts of teaching a newly founded course is having a source of feedback and assessment in order to improve it. Software, such as CATME, has often been used to gain data from the students in the form of surveys. This will be helpful in optimizing the course as it is being taught. The surveys also serve as a source for improvement by supplying the teacher with information about how students are handling assignments and group work.

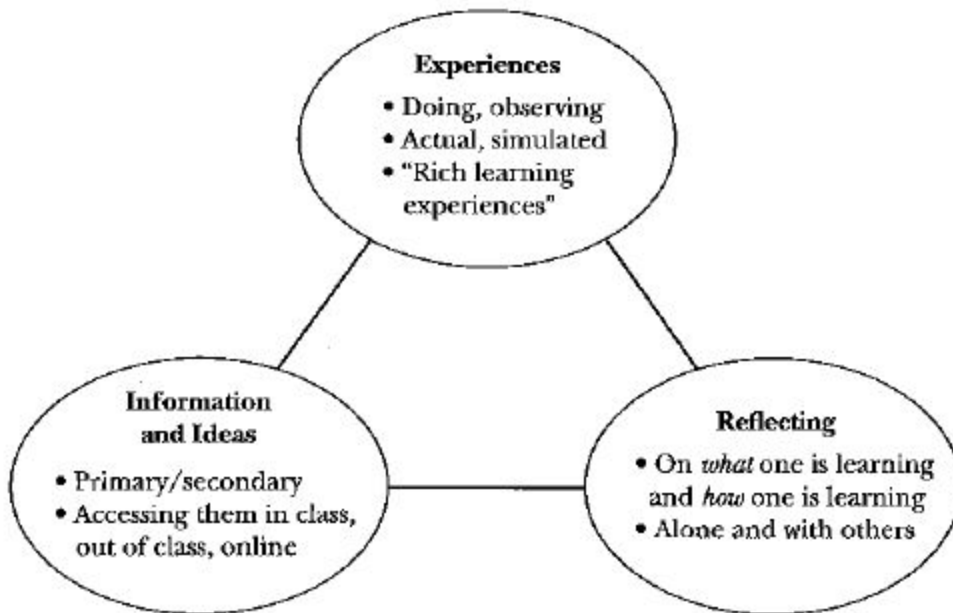


Figure 2: Holistic view of active learning (Fink, 2003)

The components above are important with respect to implementing active learning for the student. Specific activities that promote active learning, are shown below.

Exhibit 4.1. Activities That Promote Active Learning.				
	Getting Information and Ideas	Experiencing		Reflecting (on <i>what</i> one is learning and <i>how</i> one is learning)
		Doing	Observing	
Direct	<ul style="list-style-type: none"> • Original data • Original sources 	<ul style="list-style-type: none"> • Real doing, in authentic settings 	<ul style="list-style-type: none"> • Direct observation of phenomena 	<ul style="list-style-type: none"> • Classroom discussions • Term papers • In-depth reflective dialogue and writing on the learning process
Indirect, vicarious	<ul style="list-style-type: none"> • Secondary data and sources • Lectures, textbooks 	<ul style="list-style-type: none"> • Case studies • Simulations • Role play 	<ul style="list-style-type: none"> • Stories (can be accessed via film, literature, oral history) 	
Distance learning (online courses, interactive video, correspondence courses)	<ul style="list-style-type: none"> • Course Web site • Internet • Video lectures • Printed materials 	<ul style="list-style-type: none"> • Teacher can assign students to directly experience . . . • Students can engage in indirect kinds of experience at distant sites or online. 		<ul style="list-style-type: none"> • Students can record their reflections and then, if they choose, share their reflections with others in writing, via TV, or online.

Figure 3: Activities that promote active learning (Fink, 2003)

Accomplishment of the entire set of suggested activities above may be a daunting task, however, the idea of promoting active learning through these types of tools is the main objective. Instructor experience is a positive asset especially with the predisposition of running the course to effectively understand how to present knowledge as well as how to keep the student engaged. It is imperative that the course does not rely heavily on lecture-based learning but instead as a supplemental method to enhance the learning outcomes. Providing in and out of class activities for the students additionally enhances their learning experience as well as improves information retention. In order to advance the common teaching system, steps need to be taken in creating and organizing a dynamic course that pursues constructive teaching and learning.

1.5 Difficulties with Traditional Teaching Methods?

As previously discussed, one of the distinguishing factors about this course is the way in which it will be designed. That is, putting a great deal of emphasis on the hands on approach or the experimental side of the class. In doing so, the student is exposed to a more realistic and practical approach to science. This is applying the theories or analytically working through a problem to come to a solution. An approach such as this is highly beneficial to the student as there are several limiting features of learning methods currently being implemented. These can be avoided with alternative learning designs and some of these limiting factors are described below: (Yiping Lou, 2004)

- Difficulty retaining information after course is over.
- Do not develop ability to transfer knowledge to novel situations.
- Does not provide critical thinking or problem solving skills.
- Students do not achieve affective outcomes such as motivation for additional learning or a change in attitude.
- Students lack confidence in their ability to approach a problem and figure it out on their own.
- Students can feel like they aren't learning as much as they could or should be.
- Students feel as though their college teachers don't care about them or promoting their learning.
- Students do not engage fully or energetically in learning.

The *History of Biology* course design will attempt to avoid these limiting factors by encouraging active learning and other supplemental methods through its curriculum. Active learning will later be discussed in further detail.

1.6 Student Psychology and Concept Maps

Another part of the learning process that must be considered for a course such as this is general student psychology. Psychology plays a big role in the way a person retains knowledge and is able to apply it. One way the brain is able to do this is by drawing connections between topics and so a good tool for articulating the interrelatedness of ideas is through a concept map (Ambrose,2010). A concept map has a standard design by using nodes and links in a network configuration to organize and graphically represent information.

Concept maps are a very effective tool to help students understand topics more effectively by facilitating cognitive processing techniques like drawing connections between two or more topics (Novak, 1990). With respect to the *History of Biology* course, incorporating a concept map at the beginning of each topic discussion in lecture, or at the conclusion of lab, would be an useful way for students to draw useful connections.

1.7 Prior Knowledge


A large portion of student psychology in the sense of learning material is dictated by recalling prior knowledge. Prior knowledge can be an invaluable asset as it provides a student with a certain level of framework. More importantly though prior knowledge can be a major confidence booster for a student. There is a direct correlation between interest in subject matter and prior knowledge (Tobias, 1994). It has been suggested that prior knowledge can stimulate deeper cognitive processing and arousal of emotional cognition (Tobias, 1994). However, since this course is designed to mimic the historical state at which groundbreaking discoveries were made, employing prior knowledge in the laboratory would be counterintuitive. Therefore, prior knowledge will not be a central focus of the lab portion, but will be extensively utilized in the respective lectures. Recall memory has been shown to decrease greatly over time, as the information may not be useful in day to day interactions (McGaugh, 1966). With the hands-on understanding gained from lab, the student will have prior knowledge to relate new material in lecture. Additionally, since prior knowledge and recall memory are heavily dependent on time,


the most effective way of utilizing prior knowledge is by encouraging recall in the subsequent lecture. This will give students ample time to consider the lab portion, but not too much time to forget necessary details. Certain techniques to exploit prior knowledge have been researched and are suggested for the utilization in this course's lectures. One of those techniques is known as elaborative interrogation. Elaborative interrogation works by enhancing three critical learning traits; coherence, inference, and recall (Ozgungor, 2004). Elaborative interrogation is a method that encourages a student to draw connections. Activation of prior knowledge gained during previous discussions may be triggered more effectively when instructors exercise strategies using this method of teaching.

1.8 Declarative and Procedural Prior Knowledge

While prior knowledge has been cited as being a major advantage for students learning subject matter, it can also be misleading and inadequate. Even if the student has been exposed to accurate prior knowledge and it is activated in lecture, it is not necessarily going to be on the desired level for the course or applicable to the course context (Ambrose, 2010). Creating a clear distinction between various types of knowledge by designing a course that functions through active and passive learning should develop this knowledge in a satisfactory manner. With respect to the various types of knowledge, there are two different types of prior knowledge, each of which has its own applications: declarative and procedural (Ambrose, 2010). Declarative knowledge is factual by nature and includes things like concepts and definitions (Ambrose, 2010). This type of prior knowledge can be obtained through traditional teaching styles that emphasize lectures and reading course books, as well as other means. On the other hand, procedural knowledge is the application of knowledge and how to apply that knowledge (Ambrose, 2010). As the name suggests, procedural knowledge is generally obtained through actively executing a particular task that demonstrates the content of interest. The lab portion of this course would be designed to place emphasis on procedural knowledge, while the lectures would create a bridge with declarative knowledge. This combinational scheme may be a way to

ensure that each student is provided accurate and sufficient prior knowledge when the lecture portion is introduced.

Procedural  Students will critically work through the lab.

Declarative  Students will gain an understanding of why and how the procedural portion is relevant to the overall topic through retrospective discussion in a lecture-based setting.

1.9 Active Learning

Pedagogically, this course setup is best suited to facilitate the students' ability to be more engaged active learners rather than passive learners. Active and passive learning are two different approaches to education where the ultimate goal is to educate students and obtain the best quality knowledge. Passive learning typically involves lecture-based learning, when students listen to the instructor, take notes, and repeat the information to prove they have learned. During passive learning, students will also follow explicit instructions closely with little independent thought or experimentation (Collins, 1996).

Active learning, on the contrary, involves more independent decision making and thought. For this reason, this course will be run with emphasis on active learning. Through active learning, instructors will provide students with any necessary tools and background, and students must decide what information is useful and necessary. The instructor will create an environment for students to explore and learn through experimentation, in this case specifically. During active learning, students will test facts and concepts for more independent learning, all with the guidance of the instructor (Herr, 2001). This type of learning will be implemented during this course in the *History of Biology* as instructors provide some background as to resources available at the time of a specific topic to be investigated, and students will also be provided with tools to help solve a specific problem. However, students will not be given precise instructions on how to

solve a problem that scientists encountered in the past. They must think independently, designing and experimenting with original ideas.

2.0 Course Purpose and Ramifications

There are specific goals and learning outcomes that are anticipated with the amalgamation of these disciplines, history and biology. It is important to note that the ramifications of creating a course such as this reach much further than just the WPI community. Rather, it is a global endeavor in changing the way in which classes at all levels are taught with the understanding that active interdisciplinary learning is at the core of the advancement of our progressive society (Cooper. et. al, 2001). Designing one course may not make an immediate impact into how classes are taught, but it can help influence future professors to implement multidisciplinary topics and active learning into their lectures. Unfortunately, many students are under the misconception that science is not an inclusive human enterprise but rather that it is an elite controlled venture (Cooper. et. al, 2001). The reality is that science and humanities are closely related and indeed should be combined in some form to exploit the value of both disciplines. It is therefore a grand scheme which must start at the source, which is the education system. With so much stress put on the importance of STEM courses in recent educational history, there are a great deal of resources available for educational institutions to implement innovative learning plans. A top-down approach would begin implementation at the university level? The colleges provide higher education and can positively affect the outlook on human cooperation with a common goal of advancing science in the most efficient manner.

It is then, that we specify the expected outcomes for *History of Biology*. First and foremost, the class will further demonstrate the importance and relevancy of mixing humanities with science. Simultaneously, the course will provide students with an active experimental approach while considering historical contexts. Additionally, it is expected that through the challenges presented to the students, they will come to the realization that science is a human process. They need to understand that the human element has strong pertinence to the way in

which science is conducted and its significance within history. The key idea within the social aspect of this course is that the students understand how human constructs impact the discovery process. As our world comes closer together through technology, it is vital that we recognize social and historical influences. Perspectives have heavily influenced scientific progression and this will be a significant concept that students should understand.

With the introduction of any new course, a well defined curriculum must be set in place to establish the goals associated with that course. This could be carried out by creating a course with a laboratory, lecture/laboratory combination, or solely lecture-based curriculum. During the lab portion of the course, students would work in groups, using a “hands on” approach and experimenting in context with historically famous topics in biology. The class would last an entire semester, and upon completion, students would receive two credits: one for biology and one for history. This course in the *History of Biology* would meet twice a week for two hours each class period. The first two-hour class of the week would be laboratory and group collaboration based, with the second two-hour class of the week being based on lectures and group discussions. This design would reinforce the idea of active learning while encouraging the student to analytically work through problems faced in the laboratory setting. As explained, this kind of learning has been deemed greatly effective in student development and information retention. Depending on the topics specific to each week, however, this schedule would remain flexible.

The idea of a course running for an entire semester and students earning two credits for their project based work is already an implemented option at WPI. However, the ability to receive credits from different fields of study is a concept that has been implemented at this institute in the form of independent study projects. Advisors Michael Buckholt, Constance Clark, and Jill Rulfs proposed this course in the history and biology to include more classes that offer multidisciplinary approaches. Worcester Polytechnic Institute currently offers this type of course, recognized as the Great Problems Seminars (GPS), which is registered as an FY course (first year). The University of Mary Washington in Fredericksburg, VA offers a similar course titled

The History of Biology and it is described as the “Chronological development of selected biological theories and their impact on contemporary biology” (UMW, 2014). Other schools, such as Massachusetts Institute of Technology, offer courses combining history with a specific area of biology. For example, MIT offers a course called *Anthropology of Biology* (Heilmreich, 2012). Courses similar to MIT’s often do not include a laboratory section to reinforce concepts, but instead focus on engaging in debates about the nature of life. Harvard University offers a similar course entitled *History and Anthropology of Medicine and Biology* that investigates approaches to the study of life in medicine and biology through a historical point of view (Helmreich, 2012). Present day courses, like those shown above, offered in many different institutions only teach the curriculum in a lecture-based format. The History of Biology offered at WPI will include a laboratory setting along with a discussion section.

In addition to the invention and evolution of the microscope, another unit that can be developed and presented is the Miller-Urey experiment. This project will also offer insight and a presentation outline proposal into brief history of the famous Pasteur's ‘spontaneous generation’ experiment, as well as the discovery of plant transpiration. After completion of these units, students may use the second half of the semester to develop and present their own research projects.

2. Materials and Methods

2.1.1 Introduction

The principle objective for the unit design was to reinforce active learning in a multidisciplinary manner. This included the implementation of a hands on approach both in a laboratory and discussion setting. Furthermore, specific approaches can be described as follows:

- Student exposure to original scientific documentation
- Contextualization of related historical aspects
- Discussion based learning through guided instructor questions and open peer dialogue
- Emphasis on the scientific method
- Interpretation of data and results
- Reproduction of challenges faced by scientists in a laboratory setting

2.1.2 Multiple Approaches to Topics

This course takes advantage of several different styles of teaching to maximize the retention of topics, while simultaneously putting science into a historical perspective. This can be appealing to many types of students, some of which have different styles of learning. By covering a wide variety of learning methods, the student will have a greater propensity to learn necessary information.

These will include hands on learning through lab work, research learning by reading original documents, and forum based learning in which the students are encouraged to discuss specific topics. The end of the course will feature a project based portion which is meant to facilitate personal research skills. This information will be presented to the class at the conclusion of the students research.

2.1.3 Original Documentation

The works of influential scientists are easily accessible in the modern day with the help of contemporary technology. Including a portion of the course that focuses strongly on historic information will be beneficial in achieving the intended learning goals. The material was searched for through the use of WPI's Summon program and include websites such as www.nature.com, www.vanleeuwenhoek.com/letters.htm, and www.biodiversitylibrary.org.

2.1.4 Reinforcing Homework

The multifaceted learning approach to this course will feature homework assignments as a supplementary method. The basis of this concept is to import context independent learning through usage of methods including traditional homework assignments. These will incorporate doing background research by reading journal articles or other historical literature pieces in preparation for the lecture portion of a class. The goal is to make sure students are confident and intelligible while speaking in discussion sessions. Additional assignments will include written reflections on what was learned in class and completing provided worksheets. These were made based off of the Leeuwenhoek letters for the microscope unit as well as on *Micrographia*.

2.1.5 Reflective Writing

Students will be expected to produce reflective writing pieces periodically throughout the term. These will be strategically implemented after each course topic in order to reinforce the information learned during class. The idea behind this particular writing assignment was that it is designed to give the student options to showcase their own opinions and recall knowledge gained through the course topics. Section 3.1.7 provides an example of a reflective writing assignment students will be asked to complete.

2.1.6 Classroom Discussion

A large part of in-class learning will be discussion based. Engaging students to participate in open discussion forums encourages students to perceive their own stance on a given subject while also facilitating and questioning their peers' opinions. These will be driven by use of prepared discussion questions that will help guide the students during the one hour time block. The designed questions are open ended, within the confines of specific topics. Optimal classroom discussion will be supported by students preparing and being knowledgeable on the given topic through preparatory homework using background information (see section 2.1.4).

2.1.7 Concept Mapping

The importance of the concept map is to connect the discussed topics in the course and relate them to the overall learning objective of the unit. The concept map demonstrates the overall topic of the unit and connects the ideas that were learned in discussion, laboratory, and outside work through a logical and visual flow. The map designed for the microscope unit connects the different processes for magnification relative to the historical era and modern advances. A possibility includes having the students create their own concepts maps for different topics investigated in the course. An example for the microscopes and magnification unit can be found in section 3.1.2.

2.1.8 Elaborative Interrogation

Elaborative interrogation was used as a discussion tool during class time to recall learned information. Elaborative interrogation is a process by which "why" questions are asked in order to support prior knowledge while relating it to new concepts (Menke, 1994) Using this style will allow for students to discuss and reflect upon topics previously covered. Discussion sessions were designed to be facilitated by the instructor with strong understanding of the importance of

elaborative interrogation. Asking fundamental questions in pursuit of the root cause of a problem or discovering underlying reasons during discussion are examples of elaborative interrogation.

2.1.9 Ongoing Assessment

Assessing progress as the course proceeds will be beneficial to both the students and the instructor. CATME software was used to design separate surveys that would be administered periodically throughout the course. This will help monitor the learning process of individual students as well as the progress of groups in the laboratory section. The questions were designed to basically inquire about the group dynamics and the status throughout the course of a project.

2.2.1 Laboratory Design

The unit designed focused on the development of microscopes. Key components include the pre-laboratory procedures and reports. The pre-lab designed was geared towards getting the students to think deeply about how to build something that can help them visualize details that they cannot be seen with their eyes. The prelab questions start off simple and gradually become more complex, while aiming to utilize creativity.

After the pre-lab assignment is complete, the students should have gained the appropriate amount of insight required to design their own microscope. In order to prevent students from realizing that they are building a microscope, the word “microscope” is purposefully not mentioned in the assignment. This is critical because it can set up an environment similar to that of the 1600’s when cells were magnified and viewed for the first time by Robert Hooke. Students are instead asked to solve a problem: be able to view a cell by building an apparatus for magnification. By not explicitly mentioning the word “microscope”, students will have the freedom to think more creatively. During this era, a microscope with decent magnification was novel and innovative. Building one of these microscopes required creativity and skills in both engineering and physics.

Depending on the required time for the first portion of the lab experiment, another lab section may need to be allocated. In the second section, the student will be provided instructions on how to build a modern microscope using an iPhone lens as well as a Chinese water microscope. The inclusion of these two experiments will be to provide the students with more experience about how microscopes can differ, mechanistically as well as structurally but can still provide the same function. After this, a reflective writing assignment will be distributed. The purpose is to have the students reflect on their experience in the lab and comment on similarities and differences of the various microscopes they built. They will also be required to comment on how they developed their design, why they chose to build it, and discuss their results.

2.2.2 Assessment

Assessing the course is a significant task. It will result in more supportive student aid for projects as well as serve the instructor with an evaluation template of the students. CATME software was used to create surveys that would help in appointing groups and in monitoring group projects.

Proposed Questions for Formulating Teams:

1) How comfortable are you working in group settings?

- A) Very comfortable
- B) Mostly comfortable
- C) Depends
- D) Not very comfortable
- E) Never comfortable

2) How much experience do you have working in lab environments (or equivalent internship/project research in highschool or college)?

- A) A lot(3+ years in lab)
- B) Decent amount(1.5-3.0 years in lab)
- C) Some (1.0-1.5 years in lab)
- D) Barely any (.5 years in lab)
- E) None (0 years in lab)

3) What is your level of technical skill?

- A) Excellent
- B) Good
- C) Average
- D) Below average
- E) Poor

4) How familiar are you working with the scientific method?

- A) Very experienced
- B) Good
- C) Average
- D) Below average
- E) Poor

Do you have any undergraduate background in life science courses?

- A) Yes
- B) No

Do you have any background in AP history or other similar courses?

- A) Yes
- B) No

Have you ever worked in an active learning environment (class environment that promotes student engagement through various methods like discussion, hands on activities, and problem solving exercises which deviate from the traditional lecture style)?

- C) Yes
- D) No

A peer evaluation form was also designed to gather important information from students about their group work in order to detect any dysfunctional teams and problems early. This is intended to be completed by all group members/ partners individually. The evaluation form designed is shown below.



Peer Evaluation Form

Please provide accurate evaluations on both the students individually and your group in total.

Group Members:

Evaluator:

Please rate _____ below as accurately and honestly as possible.

Criteria	Weak	Satisfactory	Strong
Understood the goals/purpose of the experiment			
Was motivated and interested in the experiment			
Provided sufficient help during brainstorming time as well as the experiment			
Was inclusive with the group members			
Completed their portion of the assignment within the allocated time period			



Please rate _____ below as accurately and honestly as possible.

Criteria	Weak	Satisfactory	Strong
Understood the goals/purpose of the experiment			
Was motivated and interested in the experiment			
Provided sufficient help during brainstorming time as well as the experiment			
Was inclusive with the group members			
Completed their portion of the assignment within the allocated time period			

Please rate how well you think the group performed:

5 4 3 2 1

Please indicate how you believe the work was distributed among members:

Please indicate if you have any concerns about the group or a group member:

2.3.1 Microscopes and Magnification Lab Experimental Procedure

The main experiment for this unit will be building a microscope. A general procedure that the students will follow after they have attempted to design their own microscope is shown below:

iPhone Microscope

To build the stand microscope apparatus a $3/4''$ x $7''$ x $7''$ sheet of plywood is necessary. Measurements should be taken and marked $3/4''$ from the sides and front edges. The camera stage will be made from a $1/3''$ x $7''$ x $7''$ sheet of Plexiglas with another $1/3''$ x $3''$ x $7''$ sheet underneath it that is extended $3/4''$ over the base. The bottom piece functions as a stage for the specimens to be viewed. The whole plywood sheet should be drilled at the markings and turned over to countersink the holes. Afterwards, a hole slightly smaller than the lens should be drilled $3/4''$ from the front edge of the camera stage and in line with the bolts. Sandpaper can be used on the lens to make it slightly smaller if necessary. Make sure that the iPhone camera lens is lined up with the laser pointer lens. A shallow hole should be drilled into the Plexiglas for light entry. Then the 3 carriage bolts ($4\ 1/2''$ x $5/16''$), 9 nuts ($5/16''$) and 5 washers ($5/16''$) can be put into place (Mosher, 2011).

Water Drop Microscope

The materials used are two clothespins, a stiff piece of plastic, glue/double sided tape, a block of wood, a flashlight, a sheet of cardboard, a small square of aluminum foil, and a glass slide. Begin by cutting a stiff piece of plastic and hole punching through the center. The plastic piece is then glued to the end of one of the clothespins where the hole hangs over the end. The rest of the clothespin is then glued onto the plastic so it can be secure. One edge of the aluminum foil is then glued to the edge of the cardboard and angled so it is reflecting onto the slide. The

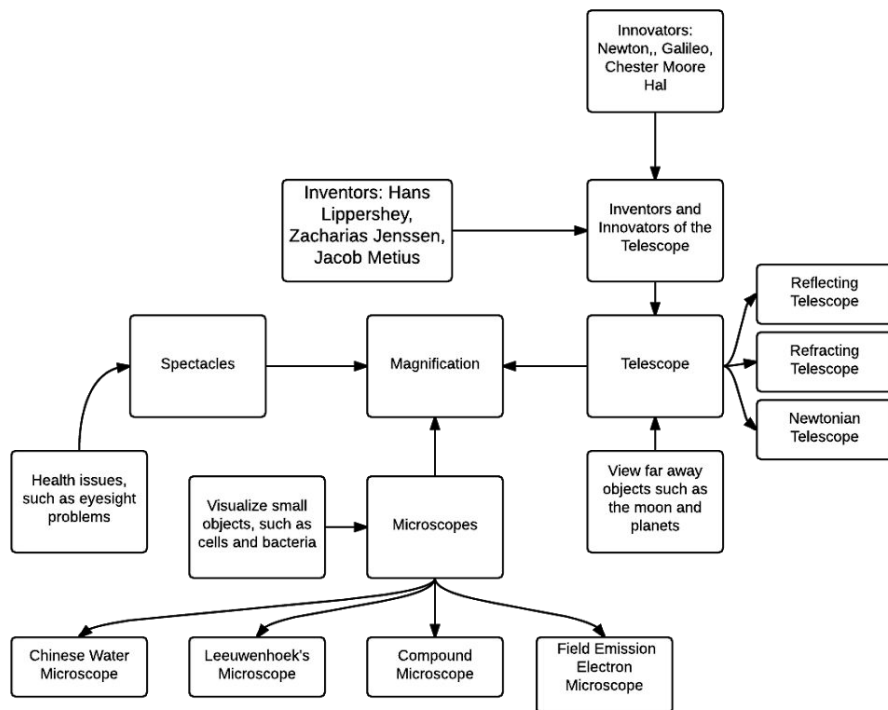
other clothespin is taken apart and put in between the glued on clothespin. Use a flashlight, or light source, to reflect off of the aluminum foil up to the water droplet (Dingley, 1995).

3. Results

3.1.1 Tentative Class Schedule and Units

Course Review	Class 1	Review syllabus, discuss lab portion of course, form groups
Looking Through the Lens: Microscopes & Magnification	Lab 1	Prelab due. Brainstorm with a group and build a microscope. Build the modern and chinese microscopes
Microscopes & Magnification	Class 2	Learn about Microscopes, Telescopes, and lenses. Discuss the <i>Long Route to the Invention of the Telescope</i>
Intro to the Guinea Pig's History of Biology	Class 2	Discussion Groups for chapter 1 and the scientific method.
Guinea Pig's History of Biology	Class 3	Discussion Groups for chapter 3.
Guinea Pig's History of Biology	Class 4	Discussion Groups for chapter 8. Problem set 2 due.
Creating Life: The Miller-Urey Experiment	Lab 2	Discuss with group how to perform the Miller experiment. Set up the apparatus and run it.
Success or Failure?	Class 5	Class discussion about the Miller-Urey experiment and how science is truly performed. Review scientific method and proper lab notebook keeping.
Disproving Spontaneous Generation	Lab 3	Discuss the theory of spontaneous generation and why it persisted.
The Survival of Plants: Transpiration	Lab 4	Discuss with groups how to assay and demonstrate the process of transpiration.
The Survival of Plants	Class 6	Discussion of the basic physiological processes associated with plants with emphasis on transpiration as conducted in lab.

3.1.2 Concept Map



The concept map above was designed to visually make connections between topics included in this unit. Links are made between the microscope, telescope, and spectacles in order to best describe the different optical designs. All possible topics can be discussed in more detail throughout the course, however only those focusing on microscope design were implemented in the unit.

3.1.4 Homework Assignments

This is an example of a homework assignment that would be given out for the Van Leeuwenhoek experiment. The questions designed were purposefully made vague and do not include answers because they are based on the student's opinions.

Name _____

Date _____

Van Leeuwenhoek reading assignment

For your assignment pick one or more of the van Leeuwenhoek letters to read. The Letters can be found here <http://www.vanleeuwenhoek.com/letters.htm>

Then answer the following questions:

1. Which letter did you choose to read? Why?
2. What was the letter about? What exactly did Leeuwenhoek see in his microscope?
3. Why do you think this letter was written?
4. Who do you believe was the target audience?
5. What are three interesting things that you learned from reading the letter?

6. Imagine you are one of the people reading this letter, at the time it was written. What would your thoughts be?

3.1.5 Microscopes & Magnification Prelab

1. What are some potential ways to increase total magnification of an object?
2. What types of materials would have been available during the time period when the first magnification devices were being invented?
3. What are the main components required to magnify the image of an object? What are some possible tools or materials that could be used for each component?

Solutions

1. What are some potential ways to increase total magnification of an object being viewed?
 - a. Placing multiple lenses in front of one another
 - b. Changing the shape (concavity/convexity) of the lens
 - c. Using different materials to create a 'lens'
2. What types of materials would have been available during the time period when the first magnification devices were designed?
 - a. Glass (not custom)
 - b. Scrap metal
 - c. Wood
 - d. Nails

3. What are the main components required to magnify the image of an object? What are some possible tools or materials that could be used for each component?
 - a. Lens- glass, water
 - b. Stand- wood, plexiglass, metal
 - c. Viewing platform- wood, plexiglass, metal

3.1.6 Laboratory Experimental Handouts

iPhone Microscope (Mosher, 2011)

Materials:

3 Carriage Bolts (4 1/2" x 5/16")

9 Nuts (5/16")

5 Washers (5/16")

Plywood (3/4" x 7" x 7")

2 sheets of Plexiglas (1/3" x 3" x 7" and 1/3" x 7" x 7")

Laser Pointer

LED light

Drill and assorted bits

Ruler

Sandpaper (if necessary)

Experimental Procedure

In order to build a microscope a lens is needed. The earliest microscope models were handmade with glass blown lenses. Unfortunately, students cannot do this without any experience in glass blowing prior to the lab. An easy solution for obtaining a lens is by

purchasing inexpensive laser pointers. The laser pointers can be taken apart and the lens can be removed and then used in the microscope model.

To build the stand microscope apparatus a $3/4''$ x $7''$ x $7''$ sheet of plywood is necessary. Measurements should be taken and marked $3/4''$ from the sides and front edges. The camera stage will be made from a $1/3''$ x $7''$ x $7''$ sheet of Plexiglas with another $1/3''$ x $3''$ x $7''$ sheet underneath it that is extended $3/4''$ over the base. The bottom piece functions as a stage for the specimens to be viewed. The whole plywood sheet should be drilled at the markings and turned over to countersink the holes. Afterwards, a hole slightly smaller than the lens should be drilled $3/4''$ from the front edge of the camera stage and in line with the bolts. Sandpaper can be used on the lens to make it slightly smaller if necessary. Make sure that the iPhone camera lens is lined up with the laser pointer lens. A shallow hole should be drilled into the Plexiglas for light entry. Then the 3 carriage bolts ($4\ 1/2''$ x $5/16''$), 9 nuts ($5/16''$) and 5 washers ($5/16''$) can be put into place.

After the model has been built, examine and draw out samples of cork, blood, insects, and a piece of food. Draw out everything to the best of your ability because cameras were not available to early scientists. Discuss your experience with fellow group members. How has this influenced your view of how science was performed in the 1800s? How does this microscope compare to the model you designed?

3.1.7 Water Microscope Experimental Handout (Dingley, 1995)

Materials:

Two clothespins

Stiff piece of plastic

Glue or double sided tape

Block of wood

Flashlight

Sheet of cardboard

Small square of aluminum foil

Glass slide

Experimental Procedure

First, cut a piece of stiff plastic and punch a hole (using a hole puncher) through the center of the plastic. Then, glue the plastic piece to an end of one of the clothespins so the hole hangs over the end. Secure the clothespin onto the block of wood using glue. Next, glue one edge of the small piece of aluminum foil to the edge of the cardboard, then angle the aluminum foil so it is reflecting onto the slide. Take apart another clothespin and put it between the existing clothespin (this will allow focusing over the water droplet). Finally, point a flashlight so it reflects off the aluminum foil and up to the water drop.

After the model has been built, use it to examine and draw out samples of cork, blood, insects, and a piece of food. Draw out everything to the best of your ability because cameras were not available to early scientists. Discuss your experience with fellow group members. How has this influenced your view of how science was performed in 2000 B.C.E.? How come these microscopes were designed so early in China? What sort of influence do you think Chinese inventions would have in Europe if they were not so isolated from them?

3.1.8 Creative Writing Assignment

Choose one of the following and write at least two pages using APA citations when appropriate.

- 1) Place yourself in the time frame of the 17th century. **Except**, you have at the disposal of your scientific toolbox the current array of technologies of the 21st century. That is, you

have the knowledge of modern technology, but it is not physically at your disposal. Within this historical context, and based off of what we discussed in class, propose a possible solution to what Leeuwenhoek solved, but in a more efficient manner. Would you find any difficulties recalling how devices of the 21st century are designed and made? What is the likelihood that you would be able to recreate modern tools and approaches? Describe some obstacles you might face in the construction of materials.

- 2) Instead, put yourself in the context of modern day. Assume a scientist of the 17th century was in the present-day, but only had the knowledge of their era available to them. How would they react to current technologies? Would they be able to advance their way of thinking? What difficulties might be faced in adapting to the advanced environment?

3.2.1 Van Leeuwenhoek's Letters

Van Leeuwenhoek was an important figure in the history of biology designing a powerful microscope during his time and being able to visualize cells amongst other things. Without him, the field of biology could have been at an impasse: only able to study living creatures at the macroscopic scale.

Leeuwenhoek was the first person to observe cells underneath the microscope. Instead, Van Leeuwenhoek had to publish to the Royal Society of London, an organization dedicated to the advancement of natural knowledge. When Leeuwenhoek initially published his findings on *animalcules* or “little animals” and the royal society was largely skeptical of his findings.

The letters that are used for class discussion and/or homework assignments are included in the appendix. Shown below is a photo of Antoine Van Leeuwenhoek.



Figure 4- Antoine Van Leeuwenhoek (“Leeuwenhoek”, 2006)

3.2.2 Hooke

Robert Hooke was alive during the 17th century (July 28, 1635- March 3, 1703) and was a philosopher and scientific researcher. Hooke was a physicist who discovered the law of elasticity (Robert Hooke, 2014). He is best known for first using the term ‘cell’ in his book *Micrographia*. He identified these ‘cells’ while examining thin slices of cork. He was able to examine these items using the microscope he built. Hooke was involved in scientific research at Wadham University in Oxford (Microscope, 2010) where he initially worked on vacuum pumps, performing experiments dealing with Boyle’s Law.

His original microscope had a design similar to those of today’s microscopes, based upon the same general concepts of refraction and magnification. The resolving power of his original microscope was estimated to have been around 100nm, judging by the detailed drawings he was able to produce from the microscope images. For further information, see *Micrographia* in Appendix II.

It is important to note the immensity of Hooke’s achievements in designing, building, and using this early microscope. During the 17th century, there were no factories to specialize parts

for his microscope. Thus, any material needed had to be designed and forged by hand to even begin building the microscope. Also, cameras were not available to capture the images seen under the microscope lens, thus Hooke showcased his impressive drawing skills and perfectly reproduced what he saw under the microscope by hand.

Shown below is an image of Robert Hooke the year he published *Micrographia*.



Figure 5: Robert Hooke (“Microscope History: Robert Hooke”, 2010)

4. Discussion

4.1 Overview of the Course's Design

The original goal of this Interactive Qualifying Project was to develop a unit for a course that strayed from the paradigm of lecture-based teaching. The developed unit and other project ideas featured a modern college course design. Although Worcester Polytechnic Institute already offers a Great Problems Seminar (GPS) course, it was necessary to design a more practical class that featured two common requirements that students need in order to graduate: a humanities and science credit. The second goal of this course was to expose students of many different types of majors to STEM based learning involving project design in their first year of college. This discussion aims at dissecting the designed elements and relating them to the initial concepts and problems in the field of education in a technological society.

The History of Biology was specifically designed in an effort to create a course that would stimulate students' interest in the sciences and increase their understanding of historically notable experiments. The semester long course implemented critical thinking skills and active learning in the introductory unit: *Microscopes & Magnification*. Incorporating the biology lab, which included experiments relating to both engineering as well as other sciences, served the important purpose of providing hands on activities to further promote active learning to the students. The CATME based surveys are expected to be very effective when implemented in the class and should help prepare student groups based on variable learning levels and experience. The group analysis surveys were also shown to be very useful in gathering team feedback and evaluations that will provide instructors with an understanding of how the students are performing.

The ability to gain feedback early on throughout the course is an important feature. The inclusion of CATME will most importantly provide professors with the ability to catch any group problems that arise early in the course. Another company that also provides surveys can be

chosen. This tool is essential especially during the first runs of the course where the majority of problems are expected to occur. Hands on History may result in controversies as it is taught with the inclusion of humanities and sciences, an equality of the two disciplines may not occur. In this case, students may receive more knowledge in one field than the other. The sequential administration of evaluations will help to monitor learning levels and provide professors with information on where the course is lacking or needs further improvement.

The second half of the semester for the *History of Biology* was designed to have students research and document their findings on a research project of their choosing. Much like a GPS, they will present their findings to the class along with other important historical details and implications involved in the project. The peer evaluation form, from section 2.2.2, will be very useful in analyzing student thinking and help the instructors manage students' group work and team effort equality among all members. This is important in being able to quickly and efficiently solve any problems that come up throughout the research project.

Training students to work in teams will provide valuable skills. Some of the core values of Worcester Polytechnic Institute are aimed at the development of group work adeptness formed by the constant growth in creativity and critical thinking skills. Students taking the History of Biology will gain all of these skills. The class will function in many ways like a GPS, but will also provide students with a deeper understanding and appreciation of how science really works. The unit and other experiments developed helped match the goals aimed by the course. The development of those experiments and lessons strived to provide the students true scientific experience that is also accompanied by the failure and obstacles associated with scientific inquiries and pursuits.

The IQP team believes that the original goals set for the class were met. The unit developed, *Microscopes & Magnification*, is analyzed in the next section in detail for its ability to be successful and why certain parts were included.

4.2 Microscopes & Magnification Unit

The discussion section of the unit incorporates both scientific and historical background on microscopes and notable scientists who contributed to its innovation and implementation in research. An important concept that students will gain through the historical background section of discussion is that scientific discoveries were often fueled by common problems present at a specific time period. One such problem can be a medical necessity. As people aged, their eyesight worsened and many inventors strived to develop lenses that would help the elderly see (Willach, 2008). Along with this, as people became more literate there was further demand for objects that would help magnify text. Understanding that the development of science is often coupled with basic necessities of a population at a specific era is important for students to grasp. This will help them dissociate from the common misconception that science is performed by geniuses that simply get miraculous ideas leading to technological innovations.

The scientific and historical discussion component also includes periods of time devoted to discussions. These discussions may be done amongst student groups or the class as a whole. The purpose of these discussion periods is to stimulate critical thinking skills. An example that was presented in the *Magnification* unit was to develop some ideas revolving around the similarities and differences amongst Newtonian, Catadioptric, and a simple refracting telescope. This sort of discussion should help stimulate the student's observational skills as well and introduce them to communicating their ideas to their peers and professors early in their college career.

The laboratory portion of the unit was designed to provide the students with a hands-on experience in order to have them better understand both the experiment and the scientific process. The *Microscopes & Magnification* lab, like some of the other labs which are included in the appendix, revolve around the concept of the students designing their own experiments. The teaching assistants (TAs) will help guide them in the correct directions when necessary, but it is mainly going to be the students that will figure out how to run the experiment. The microscope

design section will feature the students brainstorming the components of a microscope before they build one. After they have designed their own, students will be provided instructions for building a more modern microscope that utilizes an iPhone camera along with an older styled water-drop microscope. The goal is to have them understand and more efficiently grasp the knowledge behind how a microscope works and what makes different types of microscopes unique. Using this method of learning with a hands-on experience is more effective for the student's educational advancement. By building the water-drop microscope, they will learn about Chinese history, where the water drop microscope was developed. Further, a debate of why this model serves as a useful tool and how this may or may not have helped develop novel advances in microscope technology will be discussed. This will allow students to compare cultures and how needs and environment affected the technology they produced.

Another important and unique aspect of the *Microscopes & Magnification* unit is that the laboratory section will be run before the background information is provided. This will require the TA's to be better skilled in aiding the students' development directly into the subject matter. It is expected based off of research on college course design that it will be more advantageous to the student's understanding of the subject matter. It is imperative that the information offered during a course is retained and that the skills gained are not lost immediately or soon after the course ends. Having the students perform more difficult tasks without any background information is expected to have a lasting affect on them as well as improve the amount of facts, details, and knowledge they retain later when they are exposed to the lecture.

Although the *Microscopes & Magnification* unit was not tested on WPI students, due to insufficient time left to sign up people by the end of the project date, an exemption for the IQP investigation study was received from the Institutional Review Board (IRB), see appendix I, at WPI. This will allow any future students to run a test lab on *Microscopes & Magnification* as well as gain valuable data and results. It is important to find how students react to the lab and if the lab was successful at achieving the initial goals.

4.3 Possible Course Alterations

A possible solution to fixing the scheduling conflicts may be to offer this as a term long course instead of a semester long one. It may attract more students and appeal to more diverse majors. Such an option would include a deduction of the amount of credits that could be offered. It may be possible to either alter the time allotment per lab period or decrease the amount of labs offered during the course.

Because the majority of the course is aimed at hands-on learning activities, it may be more beneficial to allocate lab time than discussion time. This will step away from an uninteresting lecture themed course and be more heavily geared towards active learning.

It may be more necessary to find ways to effectively advertise the course to all majors. It could even be more beneficial to encourage freshman and sophomores to take this course in order to fulfill their graduation requirements. A key to doing so would be to have professors in all majors, the Career and Development Center (CDC), and/or advisors at WPI speak about the course and its usefulness in not only providing major requirements but also providing lifelong skills.

4.4 Unit Designs and Alternative Experiments

Three other possible experiments were created that mimicked the goals of the *Microscopes & Magnification* unit. The first of these is the recreation of the Miller-Urey experiment. The significance of this experiment is introducing students into biochemistry early in college. This class, in particular, is not offered until the third year at WPI. Being able to be exposed to biochemistry earlier in college may help some students who struggle with choosing a major. This experiment will also help students learn more about how biology was studied in the 1950s and how most scientists at the time heavily relied on physics and engineering when setting up their experiments.

The Miller-Urey experiment was published at a time when science and the ideas of the creation of life were being reformed. As scientists pursued more modern ways of thinking and researching they discovered some crucial answers for the most popular question: what were the building blocks of life? One of the first solutions to this, albeit incorrect, was that proteins contained the genetic information necessary to store genetic information. The Miller-Urey experiment generated amino acids from simple organic compounds. Amino acids chains fold into proteins and so this famous experiment provides a solution for how life can form because the results of the famous Miller-Urey experiment indicated that proteins were the first molecules formed during primordial earth (Miller, 1953). Mimicking early earth conditions, such as lightning hitting the atmosphere, and using only methane, water, ammonia, and hydrogen, Stanley Miller was able to generate and purify alanine, glycine, and aspartic acid (Miller, 1953).

Performing this experiment, as Stanley Miller did, involves an expertise in glassblowing as well as the formation of a unique distillation system. The goal was to have the students brainstorm certain reactions using simple organic compounds in an attempt to develop amino acids. There are ample possibilities for creativity in the experimental design for the Miller-Urey lab. There are several alternative ways to build a similar apparatus to what Stanley Miller designed that would result in formation of amino acids at the end of a reaction (Miller, 1953).

This experiment features working with the engineering design process. Students have the chance to go through the steps of identifying the need, researching the problem (i.e. how to make a distillation system and apply energy to it), developing possible solutions, selecting and building a prototype, testing the products formed (by thin layer chromatography), and redesigning as needed. A lab of this magnitude should run over the time frame of a week. An important note about this is that the students would not be provided with any sort of protocol, background information, or a lecture from the professors until after the lab portion has been completed. This allows for them to really experience raw science and includes how to cope with failure.

Designing and redesigning will be necessary throughout the Miller experiment. This is done to show how much scientists struggle before they get tangible results.

Another possible route to take for performing the Miller experiment lab is putting out many different types of distillation materials, gases, and other tools and having the students try to conceptualize how they can build something with available resources. This may frustrate students, but it will also help push them to think more creatively. After the lab period is run the professors will teach the lecture. This should include a discussion that will have the students communicate their thoughts and ideas about the lab.

4.5 Teaching and Learning Analysis

The most difficult and important aspect of the History of Biology class was to analyze the teaching methods implemented in the unit designed. The problems with college courses, offering both history and biology, are providing material in a lecture-based form where the professor talks throughout the class and only provides factual data. The idea to solve this was to merge a laboratory with a lecture. The solution presented in *Microscopes & Magnification* implements critical thinking skills as well as active learning. The microscope labs are simplistic and allow the students to perform creative thinking before receiving any concrete instructions. Enabling students to design and build their own microscopes complements many of WPI's core values such as developing leadership skills, research skills, and peer collaboration. Students will gain experience working in teams and using the engineering and design method. The last portion of the class will involve them designing their own project and performing the necessary research. This is important for helping them improve their skills in scientific writing.

The history portion of the class featured a creative approach to learning about important historical events that were crucial to the development of modern technology. The students will get the opportunity to get immersed into history with direct exposure to first hand accounts by scientists as they were working in the field. The Von Leeuwenhoek letters and Hooke's

Micrographia allow them to read about not only how science was performed at the time, but also about the methods that were used to analyze nature. The class discussions on their reading assignments will also help promote active learning. As the students participate in class they will be increasing their confidence while also achieving a stronger foundation for learning the material. Communicating about how scientist performed in their environments will help the students gain a better appreciation for science, while also teaching them that it is not always easily carried out. Experiments and analysis take time and effort. This is also a key thing they will learn in the lab portion of the course.

The designed unit accurately strayed from the general college class design. The important addition of having the students perform the lab prior to the class will not only allow them to gain skills in problem design and critical thinking, but also open their minds to the concept that science is an inclusive human enterprise and is not only performed by the elite geniuses. This class, if offered globally, will change the way students perceive the STEM fields. Having the history background to important developments in technology will help them appreciate research and hard work. It will also provide the students with the confidence they need in life to pursue projects and persist throughout if problems arise.

Analyzing how the students learn the material will be difficult until the course is run for a few years and the data collected through CATME along with course evaluations is reviewed. Based on the unit where the students build two different microscope models The students should effectively understand the science behind how magnification works in a lens based system that they design on their own and the two others that they build for comparison. By struggling to think of and create their own solutions to building a microscope (before they are given formal instructions on how to do so) they should gain an appreciation for the difficulty of project design as well as learn that working hard and resisting temptations to give up are the true keys to success in college and in life. The struggle in the laboratory will provide them with the experience they need prior to the lecture. The historical background will be emphasized in lecture, but in this course class discussion periods were included in order to stray from a situation

where the teacher is the only one talking. The students should be more inclined to speak about their ideas after having experienced the laboratory portion of the class. The homework and creative writing assignments will also help them assimilate all of the information that was provided throughout the course meetings. In order to help guide them, as well as prevent them from experiencing information overload, concept maps can be provided throughout the discussions or the students can design their own for each topic covered. The example made for the magnification unit (section 3.1.2) outlined some scientists and ideas that would help acquaint the students with the material.

Merging the students experience in laboratory with the historical context is expected to be highly effective in retaining the information learned after the class ends. After the course, the students will be much more qualified in the sciences and humanities and will be more cultured as people in the world. The lasting effects of the class will result in positive impacts on a student's life and journey through their other college courses.

4.6 Future Work

Continuing expansions of this IQP are necessary, as no project of this scope is without flaw or overlooked information. In regards to the unit design, we would like to propose an alternative expansion of the microscope lab that students would be required to perform. An ideal lab would consist of students being able to construct their individual microscopes from scratch, as well as simultaneously distributing knowledge through collaboration. As discussed in our unit design, it is imperative that each student is responsible for their own unique scientific approach towards the problem; a more encompassing design would draw out each student's advances as they occur for the benefit of the entire lab section. The rationale for this future alteration is that we believe a good representation of how modern science works is through communal discourse. While certain inventions, especially historically, have been made under intense secrecy, no invention or discovery has ever happened without some degree of cooperation. The modern pursuit of science has made a shift to be more inclusive of related scientific advances. It is

through this shared method that progression takes place at an accelerated pace. While our goal in this IQP microscope lab design was to create a historically accurate setting where the entire lab section would only be allowed minimal collaboration, a possible variation to this lab may actually be more beneficial to the students' learning careers. A certain historical perspective may be slightly compromised for the purpose of a team oriented approach that would accelerate microscope optimization.

The historical perspective that is highlighted in our unit design should not be disregarded. This alternative microscope lab unit proposal is merely a tweak that may or may not be implemented at the instructor's discretion. The obvious importance of peer collaboration and group work does not stop at an increased rate of scientific expansion. The potential benefits students may harness from joint work may outweigh the critical historical viewpoint gained from working individually. This alternative design is notably in accordance with WPI's ideals as being a research focused institution with an interdisciplinary, team-oriented approach to solving real world problems.

5. Conclusion

The original goals of the course featured presenting students with a class that would actively engage them. In a technological society, it is often the case where many people believe that STEM topics are only available to the elite of society. An important aspect of the History of Biology is that it presents the students with the ability of visualizing science as an endeavor of hard work where there is a lot of failure. The historical background offered in the course, along with the practical laboratory section, ensures that it will have a lasting effect on a student. Globally, this class could alter the lives of students who do not go to a technological school by allowing them to understand how science really works and make it an approachable field.

The *Microscopes & Magnification* unit embodied the active learning ideals by incorporating the engineering design process, two different solutions at building a microscope, and class discussions during the historical background information period. This new way of having students process problems before being handed the solutions will ensure that they fully grasp a subject. The long lasting effects of the course will positively enhance a student's experience in college as well as in the humanities and sciences.

In addition to this unit, a sample for another possible unit was included in Appendix 2. This focused on the Miller-Urey experiment and was chosen because it is generally unknown by first year students. It also depicts an important time in scientific history where research is truly evolving. The students can access some historical documents so they can gain an appreciation of history in the 1950's. This experiment provided proof of abiotic evolution. It also showed how a scientist's environment could alter experimentation and results. Peer evaluation and criticism was very important in altering what was accepted and what wasn't. A great historical example was when Galileo noticed that the earth revolved around the sun, not the other way around as was commonly believed by the church. He was punished for his findings and it took a while before his "drastic" views at the time were accepted.

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7. Appendix I.

I. IRB Application

	WORCESTER POLYTECHNIC INSTITUTE Institutional Review Board Human Subjects Research Exemption Application	WPI IRB use only IRB # _____ Date: _____
Principal Investigator (PI) or Project Faculty Advisor: (NOT a student or fellow; must be a WPI employee)		
Name: <u>Jill Rulfs</u>	Tel No: <u>5088315786</u>	E-Mail Address: <u>jrulfs@wpi.edu</u>
Department: <u>Biology</u>		
Co-Investigator(s): (Co-PI(s)/non students)		
Name: <u>Michael Buckholt</u>	Tel No: <u>5088316429</u>	E-Mail Address: <u>mbuckhol@wpi.edu</u>
Name: <u>Constance Clark</u>	Tel No: <u>5088315712</u>	E-Mail Address: <u>cclark@wpi.edu</u>
Student Investigator(s):		
Name: <u>Ingrid Marko</u>	Tel No: <u>508-713-2604</u>	E-Mail Address: <u>imarko@wpi.edu</u>
Name: <u>Shannon Guertin</u>	Tel No: <u>774-573-8210</u>	E-Mail Address: <u>shguertin@wpi.edu</u>
Check if: <input checked="" type="checkbox"/> Undergraduate project (MQP, IQP, Suff., other) <u>IQP</u> <input type="checkbox"/> Graduate project (M.S. Ph.D., other) _____		
Has an IRB ever suspended or terminated a study of any investigator listed above? No <input checked="" type="checkbox"/> Yes <input type="checkbox"/> (Attach a summary of the event and resolution.)		
Vulnerable Populations: The proposed research will involve the following (Check all that apply): pregnant women <input type="checkbox"/> human fetuses <input type="checkbox"/> neonates <input type="checkbox"/> minors/children <input type="checkbox"/> prisoners <input type="checkbox"/> students <input checked="" type="checkbox"/> individuals with mental disabilities <input type="checkbox"/> individuals with physical disabilities <input type="checkbox"/>		
Collaborating Institutions: (Please list all collaborating Institutions.) _____		
Locations of Research: (If at WPI, please indicate where on campus. If off campus, please give details of locations.) <u>Goddard Hall</u>		
Project Title: <u>History of Biology</u>		
Funding: (If the research is funded, please enclose one copy of the research proposal or most recent draft with your application.) Funding Agency: _____ WPI Fund: _____		
Human Subjects Research: (All study personnel having direct contact with subjects must take and pass a training course on human subjects research. There are links to web-based training courses that can be accessed under the Training link on the IRB web site http://www.wpi.edu/offices/irb/training.html . The IRB requires a copy of the completion certificate from the course or proof of an equivalent program.)		
Anticipated Dates of Research: Start Date of Research: <u>4/15/2015</u> End Date of Research: <u>4/22/2015</u>		



WORCESTER POLYTECHNIC INSTITUTE
Institutional Review Board
Human Subjects Research Exemption Application

WPI IRB use only
IRB # _____
Date: _____

INSTRUCTIONS: Answer all questions. If you are asked to provide an explanation, please do so with adequate details. If needed, attach itemized replies. Any incomplete application will be returned.

1.) Applicable Exemption Number: Please provide the applicable exemption number from the list below which best describes the reasons your research is exempt from IRB review.

Exemption Number :

Complete Text of Exemptions List
(from 45 CFR Part 46)

1. Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
2. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless:
 - a.) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and
 - b.) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.
3. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if:
 - a.) the human subjects are elected or appointed public officials or candidates for public office; or
 - b.) Federal statute(s) require(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.
4. Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.
5. Research and demonstration projects which are conducted by or subject to the approval of Department or Agency heads, and which are designed to study, evaluate, or otherwise examine:
 - a.) Public benefit or service programs;
 - b.) procedures for obtaining benefits or services under those programs;
 - c.) possible changes in or alternatives to those programs or procedures; or
 - d.) possible changes in methods or levels of payment for benefits or services under those programs.
6. Taste and food quality evaluation and consumer acceptance studies,
 - a.) if wholesome foods without additives are consumed or
 - b.) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration or approved by the Environmental Protection Agency or the Food Safety and Inspection Service of the U.S. Department of Agriculture.

2.) Purpose of Study: *(Please provide a concise statement of the background, nature and reasons for the proposed study. Insert below using non-technical language that can be understood by non-scientist members of the IRB.)*

The study will be used to test a potential engineering experiment (building a microscope) while studying the history/scientific background associated with the experiment. Being able to understand what kind of guidance future students in the class may need is necessary in order to run the lab efficiently. The time it will take to run the experiment will also be monitored along with their reactions to the study. It is important to know if they gained any intellectual value from it with emphasis on the interdisciplinary challenge of the experiment.

An anonymous and short survey will be presented at the campus center for students to fill out. Their responses will help show what students think about a semester long course in both history and biology and provide a decent indicator an



WORCESTER POLYTECHNIC INSTITUTE
Institutional Review Board
Human Subjects Research Exemption Application

WPI IRB use only	
IRB #	_____
Date:	_____

_____ expected number of students that may sign up for the course.

3.) Study Protocol: *(Please attach sufficient information for effective review by non-scientist members of the IRB. Define all abbreviations and use simple words. Unless justification is provided this part of the application must not exceed 5 pages. Attaching sections of a grant application is not an acceptable substitute.)*

4.) Subject Information:

A.) Please provide the number of subjects you plan to enroll in this study and describe your subject population. (eg. WPI students, WPI staff, UMASS Medical patient, other)

Males: 10 Females: 10 Description: WPI students

B.) Will subjects who do not understand English be enrolled?
 No Yes *(Please insert below the language(s) that will be translated on the consent form.)*

C.) Are there any circumstances under which your study population may feel coerced into participating in this study?
 No Yes *(Please insert below a description of how you will assure your subjects do not feel coerced.)*

D.) Are the subjects at risk of harm if their participation in the study becomes known?
 No Yes *(Please insert below a description of possible effects on your subjects.)*

E.) Are there reasons for excluding possible subjects from this research?
 No Yes *(If yes, please explain.)*

F.) How will subjects be recruited for participation? *(Check all that apply.)*

- | | |
|---|---|
| <input checked="" type="checkbox"/> Referral: <i>(By whom)</i> <u>Group Members</u> | <input type="checkbox"/> Direct subject advertising, including: <i>(Please provide a copy of the proposed ad. All direct subject advertising must be approved by the WPI IRB prior to use.)</i> |
| <input type="checkbox"/> Other: <i>(Identify)</i> _____ | <input type="checkbox"/> Newspaper |
| <input type="checkbox"/> Database: <i>(Describe how database populated)</i> _____ | <input type="checkbox"/> Radio |
| | <input type="checkbox"/> Television |
| | <input type="checkbox"/> Internet |
| | <input type="checkbox"/> Bulletin board |
| | <input type="checkbox"/> Flyers |
| | <input type="checkbox"/> Letters |
| | <input type="checkbox"/> E-mail |

Have the subjects in the database agreed to be contacted for research projects? No Yes N/A

G.) Are the subjects being paid for participating? *(Consider all types of reimbursement, ex. stipend, parking, travel.)*
 No Yes *(Check all that apply.)* Cash Check Gift certificate Other: candy
 Amount of compensation \$10

5.) Potential Risks: *(A risk is a potential harm that a reasonable person would consider important in deciding whether to participate in research. Risks can be categorized as physical, psychological, sociological, economic and legal, and include pain, stress, invasion of privacy, embarrassment or exposure of sensitive or confidential data. All potential risks and discomforts must be minimized to the greatest extent possible by using e.g. appropriate monitoring, safety devices*



WORCESTER POLYTECHNIC INSTITUTE
Institutional Review Board
Human Subjects Research Exemption Application

WPI IRB use only
IRB # _____
Date: _____

and withdrawal of a subject if there is evidence of a specific adverse event.)

A.) What are the risks / discomforts associated with each intervention or procedure in the study?
Potential risks include human errors that may occur during the building of the microscope that may lead to small injuries if students are not being careful or following directions. Discomfort is not expected, the experiments are straight forward and simple to follow.

B.) What procedures will be in place to prevent / minimize potential risks or discomfort?
Supervision by the group research members as well as at least one of the IQP supervisors will be held in order to insure that accidents do not happen.

6.) Potential Benefits:

A.) What potential benefits other than payment may subjects receive from participating in the study?

The experience of learning how to build a microscope and the physics behind how magnification works.

B.) What potential benefits can society expect from the study?
Understanding that science is not perfect and developing experiments can take a lot of time and effort. Most people generally take the amount of work put into an experiment for granted and only look at the finalized results, not the process. Understanding the components of a commonly used object is also important.

7.) Data Collection, Storage, and Confidentiality:

A.) How will data be collected?
The IQP group members will collect data and record it into notebooks as well as excel. Data will be based on how the students are developing ideas throughout the experiment, the time it takes to run it, as well as orally ask the students questions about their experience (see attachment 3) and instruct them to write down answers to focus questions (see attachment 1 and 2). A short survey will be presented anonymously at the campus center to collect a variety of responses (see attachment 4).

B.) Will a subject's voice, face or identifiable body features (eg. tattoo, scar) be recorded by audio or videotaping?
No Yes (Explain the recording procedures you plan to follow.)

C.) Will personal identifying information be recorded? No Yes (If yes, explain how the identifying information will be protected. How will personal identifying information be coded and how will the code key be kept confidential?)
The graduation dates and majors of the students will be recorded. Their considerations for minoring in the humanities or sciences as well as their preferences with respect to subject preferences in the form of an anonymous survey.

D.) Where will the data be stored and how will it be secured?
It will be stored as a file and secured through storage on a flashdrive, dropbox, and google account. It will also be accessible to all group members and advisors. It will not be accessible to anyone that is not involved with this IQP study.

E.) What will happen to the data when the study is completed?

It will be destroyed.

F.) Can data acquired in the study adversely affect a subject's relationship with other individuals? (i.e. employee-supervisor, student-teacher, family relationships)

The data will not affect a subjects relationship with other individuals. No names or identifying factors will be collected.



WORCESTER POLYTECHNIC INSTITUTE
Institutional Review Board
Human Subjects Research Exemption Application

WPI IRB use only
IRB # _____
Date: _____

G.) Do you plan to use or disclose identifiable information outside of the investigation personnel?
 No Yes (Please explain.)

H.) Do you plan to use or disclose identifiable information outside of WPI including non-WPI investigators?
 No Yes (Please explain.)

8.) Incidental findings: *In the conduct of information gathering, is it possible that the investigator will encounter any incidental findings? If so, how will these be handled? (An incidental finding is information discovered about a subject which should be of concern to the subject but is not the focus of the research. For example, a researcher monitoring heart rates during exercise could discover that a subject has an irregular heartbeat.)*

No incidental findings are expected.

9.) Deception: *(Investigators must not exclude information from a subject that a reasonable person would want to know in deciding whether to participate in a study.)*

Will the information about the research purpose and design be withheld from the subjects?
 No Yes (Please explain.)

10.) Adverse effects: *(Serious or unexpected adverse reactions or injuries must be reported to the WPI IRB within 48 hours using the IRB Adverse Event Form found out at <http://www.wpi.edu/offices/irb/forms.html>. Other adverse events should be reported within 10 working days.)*

What follow-up efforts will be made to detect any harm to subjects and how will the WPI IRB be kept informed?
 The subjects will be emailed after the study to make sure no harm occurred to them and the WPI IRB will be informed if any adverse findings are discovered.

Investigator's Assurance:

I certify the information provided in this application is complete and correct.

I understand that I have ultimate responsibility for the conduct of the study, the ethical performance of the project, the protection of the rights and welfare of human subjects, and strict adherence to any stipulations imposed by the WPI IRB.

I agree to comply with all WPI policies, as well all federal, state and local laws on the protection of human subjects in research, including:

- ensuring the satisfactory completion of human subjects training.
- performing the study in accordance with the WPI IRB approved protocol.
- implementing study changes only after WPI IRB approval.
- promptly reporting significant adverse effects to the WPI IRB.

Signature of Principal Investigator Michael A. Buckhalt Date 4/15/15

Print Full Name and Title Michael A. Buckhalt Associate Teaching Prof.

History of Biology
Microscope experiment
Reflective Oral Questions to be asked by group members

1. Did the general setup of this lab help to facilitate your learning skills throughout the experiment?
2. Where the focus questions difficult to answer?
3. Would you prefer to have had some background reading material available prior to the experiment?
4. Do you have any suggestions for how the experiment or procedure can be improved?
5. Would you prefer more or less guidance from TA's and/or instructors?
6. Would this lab best be suited for working alone or in pairs?
7. Please rate the course from 1 to 10 (10 being the best).
8. Would you recommend this course to a friend and if so, why?

II. IRB Approval Letter

Worcester Polytechnic Institute IRB# 1
HHS IRB # 00007374

23 April 2015
File # 15-111

Re: IRB Application for Exemption #15-111 "History of Biology"

Dear Prof. Rulfs,

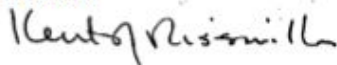
The WPI Institutional Review Committee (IRB) has reviewed the materials submitted in regards to the above mentioned study and has determined that this research is exempt from further IRB review and supervision 45 CFR 46.101(b):(1) *Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.*

This exemption covers any research and data collected under your protocol from 23 April 2015 until 22 April 2016, unless terminated sooner (in writing) by yourself or the WPI IRB. Amendments or changes to the research that might alter this specific exemption must be submitted to the WPI IRB for review and may require a full IRB application in order for the research to continue.

Please contact the undersigned if you have any questions about the terms of this exemption.

Thank you for your cooperation with the WPI IRB.

Sincerely,



Kent Rissmiller
WPI IRB Chair

8. Appendix II.

I. Extra Materials for the *Microscopes & Magnification Unit*

(700)

III. *A Letter from Mr. Anth. Van Leeuwenhoek concerning the Seeds of Plants, with Observations on the manner of the Propagation of Plants and Animals.*

IN the Seed of an *Ash* represented of the natural Size by *Fig. 1.* I observed not only two large Leaves, but that part also whence the Root takes its Rife, was extraordinary big; this part of the Seed I always found uppermost when growing on the Tree, so that the Seeds have a contrary Situation on the Tree to what they have in the Earth. These two Leaves of the Seed or Lobes were filled up with an innumerable quantity of very small Globules, except where the Fibres were visible: Which likewise were composed of much smaller Globules, and took their Origine from that part whence the Root proceeds. This supposed Root I cut through the middle, and have represented it *Fig. 2.* wherein the outward Ring represents the Bark, the next represents the woody part full of dark-coloured Pricks, which are the Fibres thereof. The innermost Oval represents the Pith, composed of round Bodies. I have likewise found that the bigness of the Seeds of Plants does no way answer to the Size of the Leaves of the Plant, there being very small Rudiments of the Leaves and Plant in the large Seeds of the Oak and Peach represented by *Fig. 3.* and on the contrary, very considerable ones in the Seeds of the *Ash*.

As I have formerly observed in the fleshy *Fibres* of the *Muscles*, that there were no Blood-Vessels intermixt with them, but they were placed only in the Membranes that encompassed the *Muscles*, and shew'd how the
fleshy

(701)

fleshy *Muscles* might be nourish'd by these Blood-Vessels, so I find the Leaves of Plants to be made up of Globules, included in the Membrane that makes the Superficies of the Leaf in all places but where the Fibres are conspicuous. The manner how I suppose these Globules, and by consequence the Leaf is nourish'd is thus: The Liquor or Sap is convey'd in the Vessel *BC*, *Fig. 4.* and is communicated first to the Globule *F*, from that to *G*, thence to *H*, and so on; as if you should put several small Pellets of dry'd Clay in a glass Vessel, if the Water touch but one of them, you will find it communicated by that to the Second, Third, and so on till they are all Wet.

I could not find any thing to satisfy my Curiosity in the small Seeds of *Figs* and *Strawberries*; possibly they were not ripe enough; for I doubt not but that they have the same parts that larger Seeds have.

And if in the small Seeds of the *Ash* (6 whereof weigh not 4 Grains) there are to be seen not only perfect Leaves with their Vessels, but the woody part also, and that from whence the Root shoots out (nay plainer than in the Walnut or Hazel) we may well conclude that the *Nature* proceeds after the same manner in all its Operations of Generation and Propagation; every Seed containing not only the Rudiments of the future Plant, but also a certain fine Flower to nourish it so long, till striking Root into the Earth, it may thence receive its Nutriment. This Flower is of an oily Nature, and the more oily the longer will the Seeds live out of the ground. And as Plants are not *Male* and *Female*, nor have a *Matrix* for the first Reception and Sustentation of the Young, so the Parent Tree produces a perfect Plant wrapt up in the Seed which the Earth receives and nourishes. I have likewise found that of such Trees as are reckon'd *Male* and *Female*, very few that bore Seeds the last year have bore any this year; so that I question
whether

whether the Trees which we find without Seeds may be therefore called *Male Trees*.

I think it now past all doubt, that the *Generation* of *Animals* is from an *Animalcule* in the *Male Sperm*: And tho I have often fancied that I have discovered the Parts and Membranes of the *Fætus* in this *Animalcule*, so as to say there is the Head, there the Shoulders, and there the Thighs, yet I will affirm nothing herein, till I shall be so lucky as to find an *Animalcule* large enough to discover this Truth, which I am not quite in despair of, since I have been so fortunate as to meet with in the small Seeds of the Ash, Leaves and Rudiments of the future Plant far larger than in the Seed of any Plant I have yet examined.

But to examine the matter a little closer: *Nature* proceeds almost after the same Method in her Operations as to the Production of *Plants* and *Animals*: For as the *Animalcule* of the *Male Sperm* cannot live in the *Matrix*, without being wrapt up in the several Coverings, and receiving its Nourishment; so neither can the Seed of the Plant subsist without continual nourishment, and has also its Coats to encompass it: And which is observable, as the *Fætus* has but one ligament consisting of several Vessels, by which it is fastned and nourish'd, so all the Seeds which I have seen have but one Ligament, made up of several Vessels also, which is sometimes longer, sometimes shorter. I will present the Reader with the Draughts of some Seeds. *Fig. 5.* *A B C* is the outward Membrane of the Seed of an *Ash*, *A D* the place where the Seed it self lies, which is taken out and represented by *E F*. *A F* is the Ligament by which the Seed *E F* receives its Nourishment, the part *A* being only joyned to the Tree; and what is more observable, the point of the Seed *F* where the Ligament is fastned, is likewise the place whence the Root proceeds: So that the Root is the last that parts from the Tree, which at first,

and has a sufficiency to provide for it self, and grow when exposed on the bare ground, and then it is no longer kept up. I say, if we consider these two Methods of *Nature*, we shall not find any other difference between *Plants* and *Animals*, than that the first wanting a locomotive Power, cannot couple as *Animals* do, and therefore must contain in the same Individual, not only the Origine of the future *Plants* which I compared to the *Animalcule* in the *Male Sperm*, but also the maternal Nourishment sufficient for it till it is furnish'd with a Root to provide for it self. This Nourishment is a sort of Flour which encompasses the *Embryo* Plant, and in the Seed makes the two Lobes.

If we compare *Plants* with *Birds*, we shall find that as in *Birds* which are Male and Female, it is necessary for the *Animalcule* of the Male already endowed with a living Soul to be placed near the Yelk of the Egg of the Female, to be thence so long nourish'd till it is fit to receive its Food from the Mother, or gather it off the Ground : So in *Plants* the *Embryo* is placed next to a sort of Fine Flour which I compare to the Yelk of the Egg, which not only defends the young Plant, but likewise affords it its first *Aliment*.

We may likewise compare the Propagation of *Trees* with *Fish*, and find the same Agreement. In fine, the Egg in *Animals* seems to be for the same use as the Lobes of the Seed in *Plants*.

Although I have formerly asserted, that the *Female* served only to afford nourishment to the *Animalcules* of the *Male Sperm*, and that *Plants* grow out of the substance wherewith they are watered ; yet I acknowledge for a certain Truth, that a great *Variety* is caused in *Animals* by the Nourishment received from the Mother. So by a Horse and She-Asse a *Mule* is generated, which is like neither, but participates of both, differing from the Horse, especially in the Ears and Tail ; since the Ass
abounding

abounding in that nourishment which produces the Ears, and wanting that which gives a long Tail, it must necessarily be like the Mother in those two particulars. So from a *White Man* and *Negro Woman* a *Mestico* is born: And from a large Pigeon or *Cropper* and a small wild Hen Pigeon, the Young are like neither; the Egg of the Female is not sufficient to nourish the *Animalcule* of the Male, so as to give it the Size of its Father. And thus Plants receive a great alteration from the different Soils in which the Seeds are planted. So *Apples* brought from *France* are with us in great esteem; and what care soever we take in the Trees themselves, yet they soon degenerate in our Soil; which change proceeds from the different Salts they meet with in the ground. And I believe if we could take the *Embrio* Plant out of one Seed and put it into another, so as it would grow, we should have a new Plant from thence like to neither: As if we should take the *Embrio* out of the *Walnut* (which I will liken to the *Animalcule* of the *Horse*) and so join it to the Seed of the *Chestnut* (which I compare to the *Matrix* of the *Ass*) that it would grow, the Plant produced by this Union would be a new and unknown Tree.

Willows are usually planted by thrusting a Stake into the Ground in wet places, yet finding several young ones on the Banks of Rivers, I judged these grew from the Seed. Wherefore in the beginning of *June*, examining the downy Seeds of these Plants, I found several brownish Particles, not much bigger than Sand; which the Microscope discover'd to be the Seeds thereof, which are contained in several little Violet-colour'd Boxes, of which in a little Sprig there were 75 placed by one another, each containing 3, 4, or 5 small Seeds, encompassed with a pappous Down. *Fig. 9.* represents these Seeds of the natural bigness. The Down or Pappous part is joined by one common Knot or Center first, and so to the Seed, and consists of 2, 3, 4, 5 or 6 small Threds, which so

X soon

the *Poplar* and *Indian Cotton*. If these distinctions of parts are so soon visible in these small Seeds, why should we doubt the production of an *Animal* from the so often named *Animalcules*. Indeed we must own our selves at a stand, when we would find out how these *Animalcules* receive Life, and that not before the *Male* has attained a certain Age; and the rather, since we hold that the matter whence these *Animalcules* proceed, was likewise in that *Animalcule* it self when it was first committed to the *Matrix*. And indeed that very extraordinary minuteness, by which one Creature is transmitted to another, is incomprehensible.

Nor can we be better satisfied as to this matter in Trees than Men; for we see plainly, that very many Trees growing from Seed are some years before they bring forth Fruit and Seeds, at least such Seeds as will produce another Plant. So that we cannot say, that that Seed which will produce a Tree depends only on the Tree; but that the substance of the Seed, by means whereof a Tree is propagated, depends on that Seed from whence the Tree it self also proceeded. And tho' we may after some manner imagine how the Fruit, as an Apple or Pear, consisting of several round Particles (to omit the Vessels) may be produced, since there are 8 or 10, it may be more Ligaments (each whereof has a multitude of Vessels) which may transmit several Juices; yet how can we conceive that the Origine of a Plant can be thus formed. So that we see the beginning of the Propagation of the Tree is to us incomprehensible, although we see it done before our Eyes; and we may suppose it after the same way as it is in Man. To conclude, the Tree after 8 or 10 years begins to bear Seed, which depends not only on the Tree, but on the former Seed: So it is in the *Male Sperme*, which has its Original not only from the *Male*, but from the *Animalcule* from

soon as the *Capsula* breaks upon the ripening of the Seed; spreads its self every way, as *Fig. 10.* tho' before the Threds were clot'd up in one, as *Fig. 11.* by which means it easily carries the small Seeds on the Wings of the Wind to great distances. Viewing these Seeds more nicely, I saw that part whence the Root has its beginning (which makes one third part of the Seed) furnish'd with very many Vessels, consisting only of oblong and round Particles. The rest of the Seed consisted of two Lobes of a dark herby Colour made up of Globules, and between these, two very small Points rising up, which were the beginnings of the Leaves of the Tree or *Embrio* Plant, which the Lobes themselves were to nourish till it should be furnish'd with a Root to provide for it self.

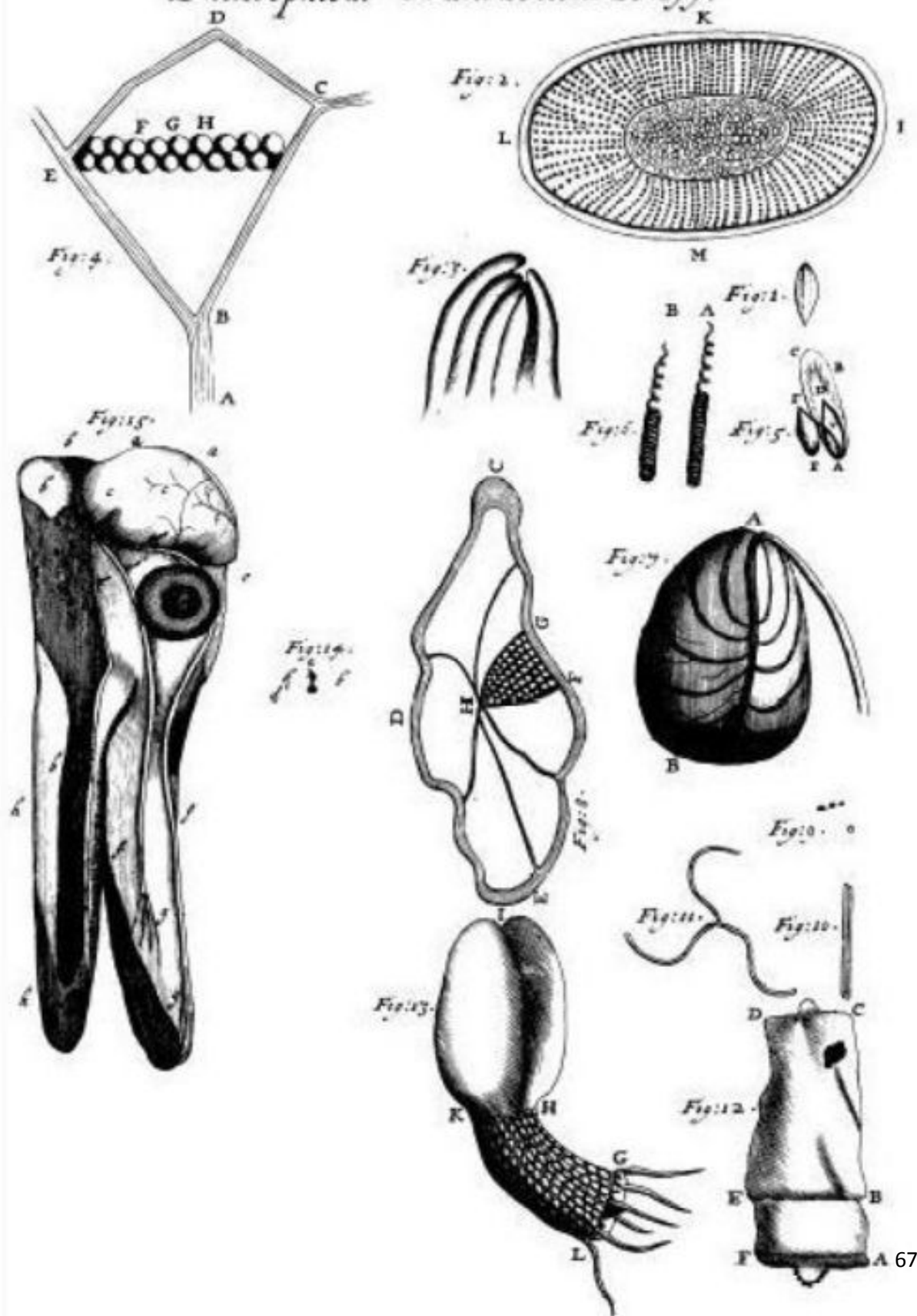
I took some of these very small Seeds, and sowed them in wet Sand in my Closet in *June*, the better to discover the manner of their growth. These Seeds being very much dried, and thereby shrunken, appeared thro' the Microscope, as *Fig. 12.* though they were not all alike, some being more, some less dried up. *A B E F* is that part whence the Root shoots forth. When they had lain in the wet Sand 36 hours, they shewed as *Fig. 13.* the Proportion of the part *G H K L* being then considerable, and in so short a time 6 Roots were shot out from it, and the two Lobes *H I K* began to shew themselves. In 72 Hours the Roots began to divide and ramify, and to take hold on the Sand. That which is observable in this Tree is, that the Seeds come to their perfect maturity before the Leaves of the Tree have their full growth, whereas other Trees perfect not their Seeds till after the Fruit in *Autumn*; so that this Tree has its young Plant grown up the first Year. The same is observable in the *Elm*; some of the Seeds whereof I gather'd in *May*, dry'd and sow'd them, and in three days they sprung up. I try'd the same in the downy Seeds of
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whence the Male its self was produced. So that the first essential beginnings of things which are incomprehensibly small, will be always hidden from us.

IV. *Part of a Letter from Sir R. B. S.R.S. to Dr. Lister, concerning the Giants Causeway in the County of Antrim in Ireland.*

Old Bawn, Apr. 24. 1693.

————— Concerning the Giants Causeway. Prolixity in a Philosophical Description I'm sure you'll pardon; for I was very exact in getting it from a person that was *rei compos*, perhaps *peritus*; a Scholar (a Master of Arts in *Cambridge*) and a Traveller, who went on purpose the last Summer with the present Bishop of *Derry* to see it. It is in the County of *Antrim*, about 7 Miles East of *Colrain*, and 31 Miles to the East of the mouth of the River of *Derry*. The Coast there is a very great height from the Sea, but rising gradually on the Land side to the edge of the Precipice, it is all cover'd with an excellent sweet Grass; when you come to the Precipice, there is no going down there it is so perpendicularly steep, but with much Labour and some Hazard it may be climb'd up. By other ways and windings one comes down to the *Strand*; in which, from the foot of this Precipice, there runs out Northward, into the Main Ocean, a raised Causeway of about 80 foot broad, and about 20 foot high above the rest of the *Strand*; its sides are perpendicular, it went on above two hundred foot to the Sea-Water; that is, it was so far in view; but as
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To conclude, there is not a Corner in all the Valley of *Noto* that is not ruined wholly, or for the most part, with a dreadful Slaughter of the People. The Southern Coasts, as *Licati*, *Terra Nova* and *Gircuti* have suffered Damage in their Buildings. And all the Castles of the Valley of *Emone* near *Mongibello* are crack'd and broken, or fallen down.

This is the Tragedy of *Sicilia*. His Excellency Seignior *Vicere* has given prudent and necessary Orders from *Palermo* for the Relief of the afflicted and miserable Remains of an amazed and half-dead People.

VIII. *An Extract of a Letter from Mr. Anth. Van. Leeuwenhoek, containing several Observations on the Texture of the Bones of Animals compared with that of Wood : On the Bark of Trees : On the little Scales found on the Cuticula, &c.*

I Some years since writ Mr. *Oldenburgh*, That I conceived the Bone to be constituted of Globules ; but finding my Mistake, I retracted that Opinion : For what I then took for Globules, was the tops of the Tubes or Cylinders whereof the Bone is composed.

Not satisfied with my Observations thereon, I continued my Endeavours to discover the true Texture of Bones ; and at length found plainly in the Thigh Bone of an Ox, that it consisted of four sorts or sizes of Tubes, whereof some are so very small and close united, as not easily to be discerned in a Bone cut a-cross, though
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with an extraordinary sharp Knife, nothing but Globules appearing : But when it is broken, some Shivers are separated, in which these *Tubuli* may be seen.

Another sort of these *Tubuli* (of which some are six times bigger than the other) are yet hard to be discovered ; for though the Knife be very sharp, yet by reason of the hardness of the Bone many Particles of them are broken and squeezed together, so as the Mouths of the little Tubes are closed up.

A Third sort much larger than the former, had nevertheless their Mouths scarce discoverable ; but I found them placed in such an Order, as convinced me, that the Ring of these *Tubuli* was the Augmentation of the Bone, as I had formerly discover'd it to be in Wood, especially when I saw, at a little distance, another Circle or Ring of *Tubuli*.

A Fourth sort exceeded the former very much, and were fewer ; so that in the space of three or four Sands I did scarce find one of them.

I have represented as well as was possible a small bit of an Oxes Thigh Bone, as it shew'd before my Glasses, *Fig. 6. ABCD*; the bit by the naked Eye was not bigger than the little Spot, *Fig. 7. EFG* is the Point of a small Needle on which the bit of Bone was stuck. I could not observe the first and least sort of *Tubuli* in this little bit ; for when the Bone is thus cut, the ends of the small Tubes are but confusedly to be seen, like irregular Globules. But the second sort look like little dark Specks, their Cavities being stop'd, by cutting which are scarce to be discerned, especially if the Knife does not cut them at very true right Angles ; for if it be ever so little aslope, it is impossible to discover these Vessels. They are represented Letter *HHH*.

The third sort of *Tubuli* are shewn by Letter *III*, and there I found not only placed in Circles orderly, but likewise in a different manner, as the large Vessels are in Wood.

The fourth sort of Tubes large, in comparison of the rest, are represented by *KK*. *LM* are several cracks or clefts in the Bone caused by the Pressure of the Knife, especially if it be not very sharp.

Besides the above-mentioned four sorts of Tubes running the length-ways of the Bone, I sometimes imagin'd I saw some in a contrary Situation, which seem'd to proceed from the middle of the Bone, and terminate at the circumference; and that these were of two sizes, whereof the smaller were such as the above-mentioned least sort, that for the most part make up the length of the Bone. The Reason why I could not well discover these, was, from their being at a great distance from each other; and some seem'd as if perforated by those that run the length-ways. And though I could not be certain I saw these radiated *Tubuli*, yet I do not question their being there; and I suppose the *Periosteum* is mostly constituted and nourished by these; the rather, since we see the same in Trees, whose Bark is formed by the transverse Fibres that run from the Center passing between the direct ones. And as we cannot determin the beginning of the Bark in the Tree, because it is annually formed anew out of all the Horizontal Vessels; so I conceive that the Membranes surrounding the Bones have their encrease from some Vessels proceeding from the cavity of the Bone to the circumference, where they are dilated into that thin soft Skin defending the Bone as the Bark does the Tree.

I know many believe the Origine and Nourishment of the Bark is from the Root; but if it were so, we should find the parts of the Bark near the Root larger, and ramify'd into smaller and smaller as they run higher, as

the Arteries and Nerves are, the further they go from the Heart and Brain ; whereas there is no difference between the Vessels of the Bark of the Root and Trunk : Besides, the Vessels of the Bark of several Trees, as the Birch, Cherry, Peach, &c. run not upwards as they do in the Ash, Oak, Elm, Nut, Apple, Pear, &c. but Circularly round the Superficies of the Tree. And all Bark whose Vessels run upwards, grows thicker as the Tree increases, the outside cracking grows Dead, and sticks to the young Bark underneath, which is the only living Part of the Bark. The contrary is evident in those Barks whose Vessels run round the Tree ; for as the Tree increases the Vessels not being able to Stretch nor Separate from each other, must necessarily break asunder ; so that the Old Bark is easily Separated and falls off from the New. Wherefore such Trees have always a very thin Bark, as is most evident in the Birch Tree.

And as we said of the Bark, that it is produced and nourisht from the Trunk of the Tree, so is it in the Production of the Skin of Animals, which is covered over with the Scarf-skin, consisting of Scaly Particles : For having examined the Skin of many Animals, it seemed to-me to be formed by the wondrous interweaving of all the extremities of the Vessels that proceed to the extrem parts of the Body ; from the ends of which, a certain matter issues forth forming the Scales ; the extremities terminating at those Scales which so long stick fast to the Vessels, till new ones displace them ; and once in the Skin of a very Fat Dog, I found a great number of Fat-globules between the branches of the Vessels that constitute the Skin.

These Observations brought me to Examine again the Scales that cover our Bodies, to find if it were possible whether they were not formed after the same manner as those of Fishes : and indeed each Scale of our Body is composed of a great company of Vessels, interwoven

R r together

together after the same manner as the Scales of Fish: Provident Nature as I have often found, performing her Operations usually after the same Method.

I therefore applied my utmost endeavours, in this Examination of the Scales of our Body, and judged those of the Mouth to be the fittest for that purpose, for that they not being dryed are more easily separable from the Skin, and from each other: Examining these divers times, I still found a clear spot in the middle of them, standing up above the rest of the Scale (which I had observed before often, but thought it accidental) whence I concluded, that the Scales, not only of the Mouth but the whole Body, were composed as those of Fishes, of Vessels, proceeding to this clear Part, and nourishing the Scales which grow from thence.

Now as to the Transpiring Parts of our Bodies, I have formerly said the moisture was exhaled from the Vessels placed between the Scales; but now I find the number of the Vessels, far to exceed what I then thought, so that by the motion and heat of the Body, there may a very great quantity of sweat be expelled by so many Vessels; the number of which I endeavoured to Calculate, by laying some of the Scales of my Skin by some Sands, so to find their comparative magnitude, and found the Axis of some larger Sands, 20 times, of others 15, and of others 10 times bigger than the Diameter of a Scale: These Scales are placed in a triple order upon one another: I took therefore the least of them and thus computed: 250 Scales as aforesaid are covered by one Sand, suppose then every Scale to consist of 500 Vessels, then will the moisture in the space of a Sand be thrust out at 125000 several little Pores, not reckoning the mouths of the Vessels between the Scales.

Examining the Scales of the Skin of my Arm I found a spot in the midst of some of them, but not so distinctly as in those of my Mouth.

I cannot well omit (in this place, relating to Transpiration) what some time since happened to me; which was an extraordinary itching on the upper part of my Nose, which viewing with an enlarging Looking-glass, I found a whitish scurfy speck which I took off, but not without some pain, it stuck so firmly to the Skin; observing it with my Microscope, I found the reason of its Scurfiness, and of its sticking so fast; for this bit of the skin constituted of Scales, was thick beset with little *Conical* Bodies, caused as I judged by a more than ordinary expulsion of a thick *Matter* or *Pus* in this place, which not being able to pass through the Scales, much less through the Vessels of the Scales, had made several pits or dents in the Skin, and forceably raised and torn off the Scales from the Skin, both which had caused the Itching and made the white scurfy speck, some part of the true skin being separated: and the little pain that I felt was caused by the fast sticking of the *Conical* Bodies to the Skin, which in separating were torn there-from; but what seemed strange to me, was that in a Days time, and sometimes sooner, a new scurfy Particle was formed like the former, beset with the same pointed parts, and this 6 or 8 times one after another, as fast as I took them off. I have given the Figure of this little bit of Skin, having never observed the like where I might well expect it, *viz.* in Leprous Persons, whose Disease is a scurfy separation of the Skin.

Fig. 8. is the bit of Skin of the true size by the naked Eye. *Fig. 9.* *A B C D* the same magnified, in which the *Conical* Bodies formed out of the *Matter* or *Pus* are observable. *E* a little hole in the *Cuticula*, through which a small hair grew. The under side of the little bit of the *Cuticula* which stuck to the true Skin is here represented.

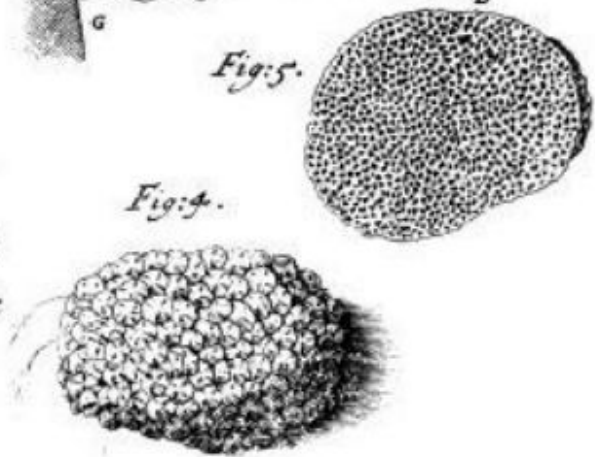
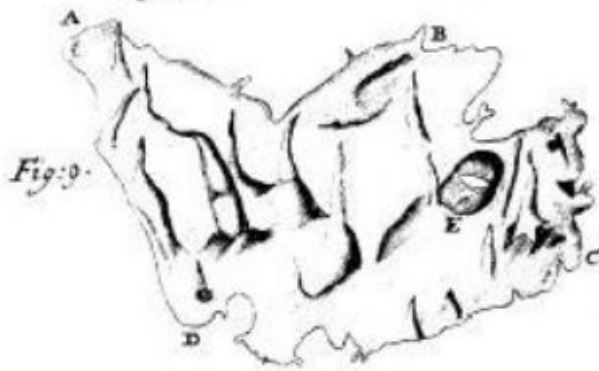
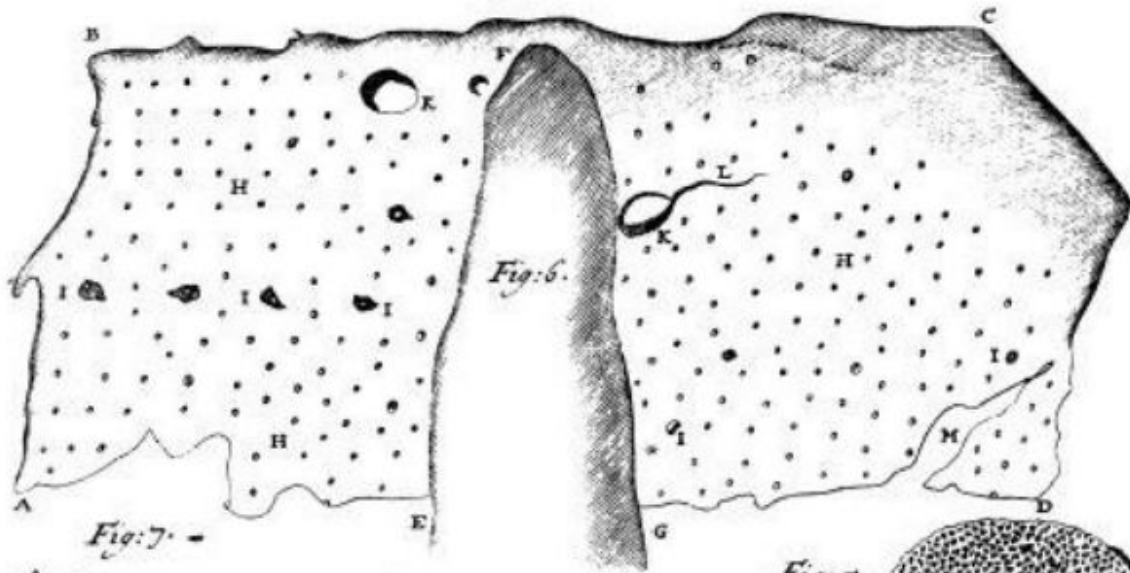
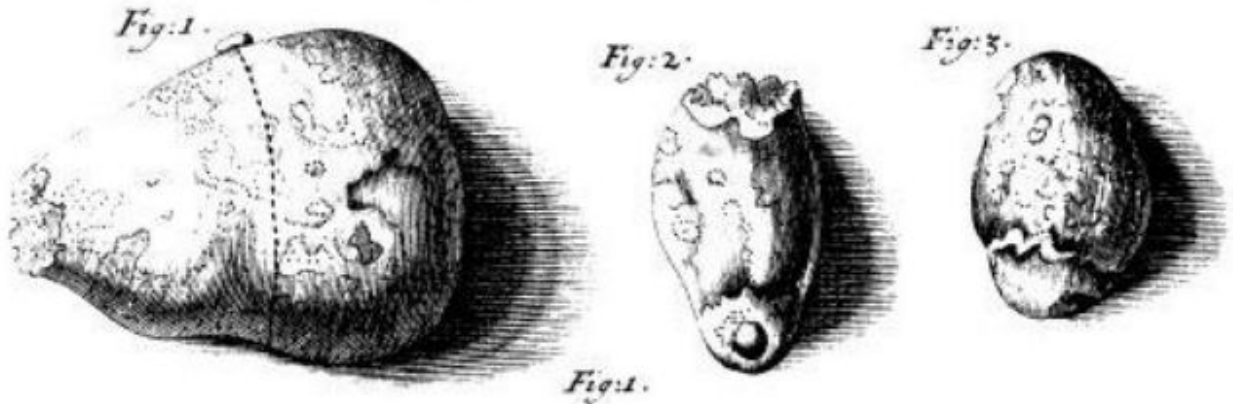


Fig:8.

II. *A Letter from Mr Anthony Van Leeuwenhoek,
F. R. S. concerning the Barks of Trees.*

Delft in Holland, *March 27, 1705.*

ALtho I have been many years fully convinc'd in my own particular, that the Bark of Trees was produced from the Wood, and not the Wood from the Bark, as many have affirmed; yet I find that some, and those persons of good Learning, do maintain the same Hypothesis; and so especially did a certain Gentleman, that was lately at my House. This induced me to make a nicer Enquiry into the Barks of Trees, in order, if it were possible, more fully to convince the World than I have yet done, that the Bark of Trees does always proceed from the Wood. I had a piece of Cinnamon Wood, about the bigness of a Quill that's used for writing, which had its Bark still upon it; I judged that this piece of Cinnamon Wood would be the most proper to prove that the Bark is made out of the Wood, because that the Horizontal Vessels of that Wood were of the same Colour with the Cinnamon itself. But as nicely as I dealt with this Wood, I could not cut it into pieces across, so as to keep the Bark and the Wood united, but the Bark would always be separated from the Wood, of which I could not understand the meaning, till I call'd to mind that the Island of *Ceylon* is situated between the 5th and 10th Deg. of Northern Latitude; so that the Fruits, Wood and Bark are of a continued whole years Growth, whereby new Saps and Juices are always carried up between the Wood and the Bark, in order to make the new Wood and the new Bark. For this is the reason that the Bark of Cinnamon is so easily separated

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from the Wood.—Wherefore, not finding my account in this Experiment, I turn'd my thoughts upon the Bark of Cherry, Plumb, Beach-tree, &c. the Vessels of which Barks are not extended lengthways, but circularly about the Wood; and in order to demonstrate the same, I cut off this small Twig of a Cherry-tree.

Fig. 1. ABCDE represents a thin Twig of a Cherry-tree, in the Wood of which the Canals or Vessels of the Bark, by which the same is fed, are not extended lengthways, but circularly about the Wood; for which reason the Bark of the said Wood can't be stripp'd off longways, but only circularly, contrary to some other Woods, as in the aforesaid Figure; where by CFG, a small piece of the same Bark, as it is stripp'd off, is represented; in which you may observe, that the Canals or Vessels, of which it is compos'd, run from C to F, or from D to G.

I have asserted formerly, that in all Countries where there is any Winter, so far as to put a stop to the Growth of Trees, at all times as long as the Growth endures the Bark grows thicker, and that the New Bark does protrude that which was made before further and further from the Wood; insomuch that in the Barks of Old Trees, one may cut a Fingers Breadth in Depth before one can come at any thing like Greenness or Sap: And if one consider these Barks with care, one shall discover what part of the Bark from time to time is deprived of its Nourishment, and consequently what part of it is quite dead.

By these my last Observations, I have discovered in a Twig of a Cherry-tree of one years Growth, that the Bark does consist of at least six thin Membranes, whose exceeding thin Vessels or Fibres extended themselves circularly about the Wood, and those Membranes were very closely united to one another.

I placed one of these Membranes, that was as nicely separated from the rest, as it was possible for me to do, before

(1845)

before a Microscope, and caused the Painter to draw it as it appear'd to him, as you may see in Fig. 2. H I K L, where you may observe the Vessels or Canals do not run longways, but circularly about the Wood; which being so, the said Vessels can't remain long whole, but must from time to time be broken in pieces.

When I cut cross the Wood of a Cherry Tree, which was about a year old, in order to shew the Painter the Horizontal Vessels that are derived from the Wood to the Bark, and whereby the Bark receives its Growth and Nourishment, the Bark, by reason of the Softness and Flexibility of those parts that lay next the Wood, did always yield so much, that it was impossible for me to shew him the said Vessels.

Upon this I turn'd my Thoughts upon the Beach-wood, because the greatest part of that Wood is clothed with a Red Bark, which sticks close to the Wood, and grows yearly thicker; and upon the outside of that Bark there is produc'd a Whitish sort of Bark several times in a year, which falls off from the Wood as if 'twas pill'd; but this only happens in Beach Wood of an ordinary thickness; for in the thickest Wood this Peeling or Scaly sort of Bark is not produc'd, and then the Bark grows exceeding thick; but the most part of such Bark is thrust away, and remains as it were without Nourishment; and in such there is no outermost Scaly sort of Bark produced.

I steep'd this last mention'd Wood in Water, because it was very dry, that I might the better cut it through with a sharp Knife, whereby the Ascending and Horizontal Vessels or Canals might receive the least damage in cutting.

Fig. 3. LMNOPQR represents a small particle of the last mentioned Wood, as it were cut across, in which the Ascending Vessels or Canals, both great and small, are easily seen, and between which run the Horizontal Vessels, which receive their Juices from the Ascending ones.

(1846)

After several cuts made with a sharp Knife, I found the Bark of the Wood to be exceeding hard; and this was mostly occasion'd, as I imagin'd to my self, by a Coagulated Whitish Matter, which one would take to be Rosin; the hardness of which hindered me from cutting the Wood and the Bark so easily together, as not to hurt the Horizontal Vessels which were continued from the Wood into the Bark in a Right Line; for the Bark being much harder than the Wood, always yielded to my Knife.

Wherefore I cut off as well as I could a small piece of Wood and Bark at one cut, and placed the said piece before a Microscope, that the Painter might view the Wood and Bark together.

In the said Fig. 3. by QUTSR is represented a Particle of the abovementioned Bark, in which the Horizontal Vessels, as they lye in the Wood, and are continu'd on to the Bark, and from whence the Bark is produced, are shown by NMOP, of which N and O do not go quite throughout into the Bark, by reason of that hard Matter which we mention'd before, and which you may see in X.

But the Horizontal Vessels, that are described by MRS, and PQU T, go throughout the Wood into the Bark, so far as to preserve the Bark from any Mortification.

Now as the Bark of the Beach Tree, or rather its Vessels or Canals, run circularly about the Wood, I could not at first conceive how those Canals could be produc'd out of the Horizontal Vessels; but at last I discover'd that as the Horizontal Vessels are continued from the Wood into the Bark, so they spout out from every side of those Vessels exceeding small Canals, which run circularly about the Wood, and so for the most part produced the Bark of that Wood.

In the said Fig. 3. I have represented by PQU T one of those Horizontal Vessels, as they are continu'd from the Wood, and carried on into part of the Bark, which

is

(1847)

is described by QUT, and between Q and U I shew a few of those Vessels which sprout out of the said Horizontal ones, and run circularly about the Bark ; and how nicely soever I observed them, I could not discover one Ascending Canal, which must needs run lengthways up the Bark, in case the said Bark had its Rise from the Root of the Tree.

I placed also a thin Scaly Particle of the Bark of the said Wood before a Microscope, which I caused likewise to be drawn as in Fig. A 4. ABCD, the Vessels or Canals of which run also horizontally from A to B, or from C to D.

But you must not imagin that this and the preceding small Particle of Bark is so open as is here represented, but conclude, that the Vessels which run circularly about the Wood are only describ'd, and that these Vessels at first lay close to each other, but as the Wood grew greater, they were separated more and more from one another.

Fig. B 4. W X Y Z. shews also a little Scale of the Bark of the Twig of a Tree, in which the Vessels describ'd by W X or Z Y do also run circularly about the Wood, but I have forgot to what Tree it belong'd, it having been some time drawn before I took any notice of it.

After these Observations, I remembered that I had lying by me a piece of the Bark of a Cinnamon Tree, which was given me by an Officer that had been a Prisoner at *Candi* in the Island of *Ceylon*.

This piece of Cinnamon Bark was near 8 inches long, a small part of which is represented by Fig. 5. E F G H.

I judged by the division, which I observ'd between I and G, and which was the thickness of the Bark, that the Cinnamon Tree to which this belonged, was very near 12 years old, and according to the same remarks, that the Tree was about 6 inches diameter.

I have several times examined the outside of this Bark, and always found it was so weak or brittle as if it were partly

(1849)

We see moreover, that the aforesaid Parts have often contained in 'em a Matter of different colours, which colours are wholly separated from each other, and appear as in N R S, and where no colours are to be perceived in the said Figures, there they are Transparent.

These long Transparent Parts, as also those that are colour'd, together with the Horizontal Vessels, which are almost all of 'em filled with a colour'd Matter, are in my Opinion the sole Ingredients of the abovementioned Bark or Cinnamon.

In the said Fig. 6. O P Q represent but a part of the Horizontal Vessels, that lye by one another.

All the said long Particles, which in a great measure compose the Cinnamon Bark, are not incurvated, as in Fig. 6. but a great many of 'em are extended in Right Lines, as you may see in Fig. 7. A B C D E F G, which represents a very small Particle of the abovemention'd long Parts, which likewise incloses some Horizontal Vessels; and wherein you may see at A how regularly the sharp Points are ranged by one another, as also between B F and C E, between which the Horizontal Vessels are to be seen in that order in which they always lye.

That sharp and pointed Particle that is represented by F H, seems to be out of its place; and I fancied that in dividing it from the other Parts, I might have broke it off at F.

I also placed 3 other long sharp pointed Particles before a Microscope, as in Fig. 8. I K L M, in which you may also see in how regular an order the pointed parts appear, as in K M for instance; from whence we may conclude, that all the other parts of the like Nature are disposed in the same manner.

I moreover cauled the Painter to draw another Pointed Particle, that was exceedingly incurvated; which, I suppose, might be occasion'd by its having surrounded two several Divisions of the Horizontal Vessels. See Fig. 9. N O P.

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We may pretty easily conceive how one Canal is produced (or comes out) from another, but how the said long sharp pointed Particles, represented by Fig. 6, 7, 8 and 9 are produced, is, as well as a great many other *Phenomena*, past my Understanding.

I have moreover examin'd into the Nature of the Bark of a thick Lime Tree, the rather because I know no other Barks of Trees whose parts are so easily separated from one another, either in length or breadth; insomuch that they make thereof in *Muscovy* Mats for Packing, and Rope-work, which is very strong, and if I am rightly informed, is not easily subject to rot, tho' it should lye long wet.

This Bark I also cut across, in order to discover the Bent or Run of the Horizontal Vessels that come out of the Wood.

Fig. 10. ABCDEFGHI represents a small Particle of the Bark of a Lime Tree, as it was cut across, where, by ABC are shown the Horizontal Vessels that come out of the Wood, and consequently these Vessels are cut lengthways.

These Vessels, altho at their first coming out of the Wood they lye close to one another, as from A to B, and from B to C, yet they don't remain always so close, but as the Tree grows thicker and bigger, the Horizontal Vessels are more divided from one another; as for instance, that which at B is but one Bundle or Collection of Vessels, with the Increase of the Tree divides itself into two, and the Separation grows larger and larger, as in BMK and BML.

Now, that there may remain no Interstice or Vacuity between the said Horizontal Vessels, there are other Vessels produced from those, as you may see between MID, which new Vessels produce a Matter that fills the Place of MLK.

These Parts are Roundish, but so interlinkt with one another, that they serve for Canals; they appear'd so
small

small to the Painter, that if he had not drawn 'em bigger than they were, you could not have made any Judgment of them.

These Horizontal Vessels don't run through the thickness of the old Bark, for in some places the Bark dies sooner than in others for want of Nourishment, insomuch that you may perceive in the Bark of a Lime-Tree of an ordinary thickness, three distinct Crusts lying one upon another; the outermost of which being destitute of Nourishment, by little and little become dry and wither'd.

I shall never suffer my self to be perswaded that the great number of descending Vessels which are discovered in the Bark of a Lime Tree can proceed from the Root of the said Tree, but depend on the horizontal Vessels of the same, which by reason of their exceeding smallness are hardly visible in Fig 10. For if the Nourishment of the Bark does proceed out of the Root, the Bark would never perish unless the Tree did also, whereas we see that in some Trees the greatest part of the Bark is dead or wither'd.

I took a small slice of the said Bark and cut it across, and placed it before a larger Microscope, and caused the Painter to draw it as well as he could, who affirmed to me 'twas impossible for him to describe all the small Holes or Orifices which he saw.

Fig. 11. N O P Q R S represents a very small Particle of the Bark of a Lime-Tree, wherein are shown partly the mouths of the Canals that lye lengthways in the Bark, and are here cut across, but chiefly to give you a view of the horizontal Canals, as they are cut in their length, as at N S or P Q; the which horizontal Vessels are represented in Fig. 10. by A I H, B M L G, B M K F and C D E.

These Canals, or Vessels, described by N S or P Q are not of a continued Hollowness throughout, but rather seem to consist of Oval Particles linkt to one another.

I have been thinking with my self whether each of the aforesaid Oval Particles were not provided with a Valve, which Valves make them appear like so many Oval Figures; and the use of which Valves might be to hinder the Juices or Saps, which by the force of the Sun are raised up into those parts, falling down or descending, after the Sun set; especially if we consider, that by the said Canals there must be caused so strong a Protrusion, in Spring time, as not only to thrust away and separate the Bark from the Wood, but also to burst the outermost parts of the Bark, that are already hard, dry and wither'd.

I have said before, that the Horizontal Vessels or Canals in Cinnamon are Hexangular, which Figure is the most perfect, and takes up the least room or space; from whence I conclude likewise that the Horizontal Vessels in Fig. 11. are likewise Hexangular, tho I did not see them lying in the same order; for when I examin'd into the Horizontal Vessels or Canals of the Cinnamon, I found that they were of the same Configuration as in Fig. 11. NS and PQ, viz. that they consisted of Oval Figures.

I had placed before a Microscope a little bit of a Lime-Tree, which was cut off of the Wood lengthways, and the Horizontal Vessels cut across, to the end that you may see how those Horizontal Vessels or Canals lye in the Wood; the which Vessels are also continued into the Bark, so far as it is alive, and serve for the feeding and increasing of the same.

Fig. 12. ABCDEFG represents a little slice of the Lime-Tree Wood, in which you may count in 9 several places the Horizontal Vessels or Canals that are cut across, and which Canals are situated between the small ascending Vessels, which for the most part do nourish the Wood. Now between the Horizontal Vessels and Canals in the Wood and in the Bark there is no difference, but in the Ascending Vessels and the Bark there is a difference; for

they are of such a Disposition as the Horizontal Vessels which are in the Wood and the Bark; and thus they agree with those Vessels described in Fig. 11. by NS or PQ.

Now if we find that the Horizontal Vessels or Canals, as well in the Wood as in the Bark, are of one Contexture, and that the Ascending Vessels in the Bark of a Lime-Tree are also of the same, we may more firmly conclude, that the Bark is produced from the Wood, and not from the Root.

I have moreover turned my thoughts again upon the consideration of Cork, which is said to grow as the Bark of a Tree upon a certain sort of Oak in *Spain*; which if it be so, I imagine that the Burning which we perceive in the Leaves of Cork, is done by 2 hot Iron Plates, in order to make it flat and strait.

I took then one of those pieces of Cork which are cut into Stoppers for Bottles, as is described by Fig. 13. ABCDEF.

In this piece you must suppose that BG is the part that lay next the Tree, and that E was the outside of the same.

In the said piece of Cork, between GHIKE, I observ'd five distinct Divisions, running across from F to D, which is the part that surrounded the Tree; and from whence I conclude, that the Cork was arrived to such a thickness in 5 years time, for each Streak denotes the growth of that year.

I observ'd also 4 distinct dark strokes, of which GI is the middlemost; I supposed they were great Canals, but could not conceive to what end they were made; but I concluded from thence, that in case these great Canals had not been so cut through lengthways, the Cork would not have been so thick.

We must likewise conclude, that the length of all Corks (in order to prevent either Moisture or Air from

passing thro them) must be consonant to the length of the Cork as it grows upon the Tree, and so that part of the Cork represented by A B C was the lowermost part, and D E F G was the uppermost or near the uppermost, according to its situation upon the Tree.

Now for my own and others satisfaction, I cut a little piece of a Cork as from G, where you may suppose that it was joyn'd to the Tree, that is to say, I cut it after such a manner, that the cut of the Knife went from G to H; and having placed the said piece before a Microscope, I perceived all the Canals so placed as if they come out of the Wood, without discovering in the least any ascending Vessels, tho I cut it never so often; from whence I must conclude again, that the growth of the Cork proceeded from the Wood.

Now to give you a better Idea hereof, I have caused the Painter to draw a small Particle of the Cork.

Fig. 14. L M N-a O P Q b, shews a small Particle of a Cork, as it was cut off between G and H, of which L M N we must suppose to be the part next the Tree, and so the Vessels or Canals, by which it receives its Increase, run horizontally, as from L to Q, from M to P, and from N to O; but I could not find one single Canal that was perpendicular, or can be said to proceed from the Root.

These forementioned Canals have no thorough passage, and it seems to me that in each Canal there are so many Valves as there are Horizontal Vessels in them.

In the said Figure by a b, is represented a Line running quite across and something incurvated, the which Line is that part of the Cork, where, the Season of the year being over, a stop was put to the growth thereof.

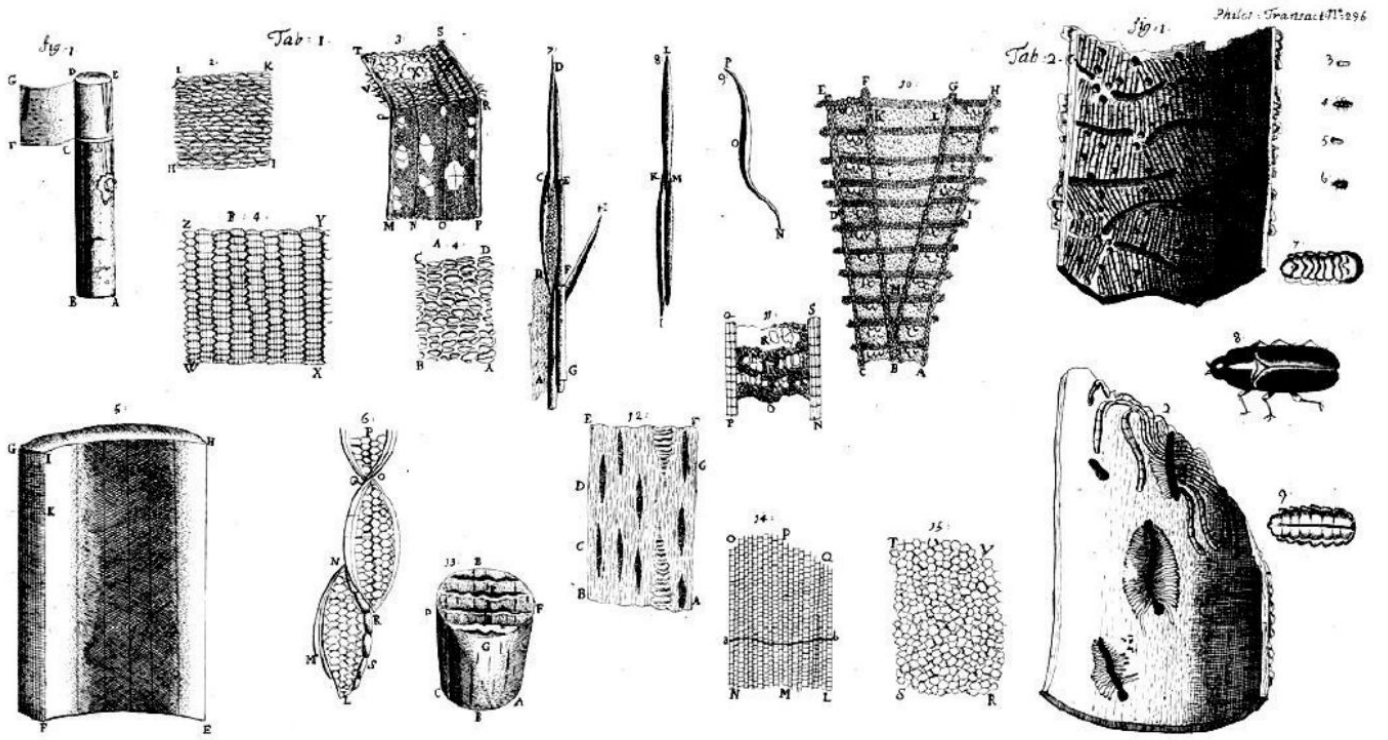
For further satisfaction, I cut another piece of a Cork after the same manner, that whereas in the foregoing Figure, the Horizontal Canals were described in the length, now the same Canals were cut across.

(1855)

Fig. 15. R S T V represents a little piece of Cork, as it appeared thro a Microscope, that was more magnifying than the former in Fig 14. this piece of Cork was cut off from Fig. 13. between B and G, and was that part that was next, or that was united to the Tree, and from whence it receiv'd its Increase, and consequently then were those Canals which in Fig. 14. were cut long ways, but now across.

In the said Fig. 15. you may perceive that almost all those parts that were cut across did not consist of round Canals, but of hexangular ones, which is agreeable to the most perfect order, because it prevents all the vacuities between them; and I imagin to my self, that in case one could procure a piece of Cork, before it had been made strait and flat, after the abovementioned manner, we should see the Canals so cut across, as in Fig. 15, between R S T U, much more perfectly than we now do. Whereas by the bending it to make it strait, a great many Canals are displaced and disordered; as in the cutting of it with a Knife the exceeding fine Membranes, of which the Canals are compos'd, are often torn and broke to pieces.

This is what I have thought fit to trouble you with about Cork, but if I were Master of that Wood which produces it, I should receive greater satisfaction; whereas I cannot now conceive how the vast number of Horizontal Vessels which are seen in the Cork, and of which the whole Cork consists, can be produced by the Wood thereof.



II. *Microscopical Observations on the Blood Vessels and Membranes of the Intestines. In a Letter to the Royal Society from Mr. Anthony Van Leeuwenhoek, F. R. S.*

Delft in Holland, April 20. 1706.

I Take the Liberty to acquaint your Honours, that Professor *Bidloo* came to my House *March 7.* desiring me that he might view thro' a Microscope a little piece of Gut, which, he said, was part of the Bowels of a Woman; whereupon I having separated a small Particle thereof from the rest, we discovered in one of the thin Membranes, of which, for the most part, the Gut is composed, a great number of little Fibres and Vessels, which lay in great Multitudes over and across each other, as also some Particles of Fat, which lay like Bunches of Grapes upon the said Fibres.

After that the said Professor *Bidloo* was gone, I was desired, that in case I had discovered any thing remarkable in that little piece of Gut, I would give a brief Account of it.

Whereupon the same Evening I writ to the Persons who desired that of me, that I was considering whither or no those Particles of Fat, which we had discovered, might not be supposed by many People to be Glands or Kernels, and that the same were to be found likewise in the Skin; and the rather, because that I have discovered in the Skin and Guts of Animals none of those Glands, of which People talk so much, but Particles of Fat in great number.

Mr. *Bidloo* having acquainted me how this Woman died, I writ to him thereupon, as follows,

When I observed that little piece of Gut, that was unprepared, nicely thro' my Microscope, I could perceive a great Quantity of Blood lying without the Vessels, which I never did discover in the Guts of other Animals before; from whence I concluded, that as a great many Animals lose their Lives by the spilling of their Blood, that same Blood, notwithstanding the quicker Motion of the Heart in the Pangs of Death, continues its Circulation: Whereas in those that are Hanged or Strangled, as this Woman was, the Circulation of the Blood is in a great measure interrupted by the Rope: To which, if you add the dismal Thoughts of approaching Death, upon Account of the deserved Punishment they undergo, (which Thing does not occur in Beasts) and the great Concern at that time, there will be a much greater protrusion of the Blood of a Rational Creature, than that of a Beast.

Now the Blood being protruded out of the Heart in great Quantities at once, and not being able to circulate with the same quickness thro' the small Vessels, I suppose that the Tunica's or Coats of the exceeding small Vessels are so extended, that the Blood filtrating thro' them, is found in great Quantities without the Guts, where it is dried upon the extream Membrane or Skin, and is found in little Lumps here and there without any Order.

Soon after this, having acquainted Professor *Bidloo* with these my Thoughts, he had the Goodness to send me, on the 12th of *March*, two Dissertations subscribed with the Name of *Peter Evertse*, in *Latin*; from whence a day or two after it was explained to me, that the Woman to whom that Gut belonged had been Hanged, and that in her Life-time she was troubled with a Falling-Sickness.

In the said Dissertations I observed three distinct Draughts of the Figure and Form of the said Gut, and taken by the help of a Microscope; and forasmuch as these Figures did not agree with my Observations, I have taken the Liberty to delineate some small Particles of the said Gut, just as they appeared to me thro' several Microscopes, hoping that it will not be taken ill of me.

I then placed a small Particle of the said Gut with the Outside thereof before a Microscope. to shew how the Blood lay coagulated upon the extream Membrane of the said Gut which was unspeakably thin.

Fig. 1. A, B, C, D, E, F, shews the Blood as it lay spread within a small Compass upon the outmost Membrane of the Gut.

By G, G, G, G, we represented the Oblong sort of Drops, where the Blood had been protruded in an extraordinary thickness, and was coagulated like that Blood that lay upon those Parts which are described by B, C, D, E, and F.

Now as we see how this Blood was protruded thro' the Vessels of the Gut, we may very well suppose that the same happens in other Parts of the Body.

After this I separated the Membranes of the Gut, so carefully from one another, that I imagined I was come to the innermost Membrane; but after that I had observed it with great Curiosity, I discovered that that Membrane which is here described by *Fig. 2*, H, I, K, L, M, N, O, P, Q, which is the Circumference of it as it appeared to the Painter, was a double Membrane.

In this small Particle, which was drawn thro' a larger Microscope than that of *Fig. 1.* there were such a vast number of small Vessels and Fibres, that it is almost inconceivable, as it was impossible for the Painter to describe all those that he saw of them, especially by reason of those two thin Membranes lying one upon the other; for how thin a Membrane soever one places be-
fore

fore the Microscope, if it be not broken, one can discover not the least Hole or Passage in it ; and when one of these small Fibres or Vessels appear to the Eye, they disappear as soon and escape the Sight ; partly because they are cover'd by other Particles that lie by or near them, and partly because they are torn from the Membrane that lies upon them, to which they had been before united.

By L, M, N, O, are represented the little Vessels or Fibres, which by being separated are standing out of the Membrane.

Now as for those Vessels which are discovered in the aforesaid Membranes, it is impossible for me to judge whether they are Arteries, Veins, Lacteal, or Lymphatick Vessels ; for altho' there are divers Arteries and Veins in such a thin Membrane as is here represented, and tho' there were Blood in them, yet cannot that Blood be discovered, because in such fine Vessels it loses its Colour ; besides the Globules of Blood in such exceeding small Veins and Arteries, if they are not dissolved of themselves, yet by the Expansion of the Gut to bring it into a flat posture, they must necessarily be dispersed and dissolved.

In the said Figure by R, R, R, R, R, and upon more other Places are represented the little Globules of Fat.

I placed before another Microscope a little Particle of the said Gut, in which, to the best of my Power, I had separated the Membranes that lay upon one another, and that compose the thickness of the Gut, in order to see them the better.

In *Fig. 4.* By A, B, C, D, E, M, P, W, *a, b, c, d,* X, Y, R, O, L, is represented a small Particle of the Gut (because it should it should not take up too much Paper) wherein none of the Parts are described, because it is only to shew how the Membranes are separated from each other ; the Circumference of the extreamest Membrane, of which, together with the Coagulation of the Blood

upon it after it had been protruded thro' the small Vessels, is represented by A, B, C, D, E, F, G, H.

The uppermost Membrane is of an exceeding thinness, and very near of such a Form, as in *Fig. 2*.

In the abovementioned *Fig. 4*. A, G, F, I, K, L, is represented the third Membrane; L, K, I, M, N, O, the fourth; O, N, P, Q, R, the fifth; P, T, V, the sixth; P, W, X, Y, the seventh; and by W, *a, b, c, d*, the eighth Membrane.

So that the abovementioned Gut, as far as we have been able to represent it here, consists in Substance or Thickness of eight Skins or Membranes lying upon one another.

Between two of the said Membranes I observed, that there lay some Fibres without any Branches or Sprigs proceeding from them; and pursuing my Observations, there occur'd to my sight some other small Fibres lying close to the rest, which seem'd to me to be torn from other Parts; and a little on one side there lay one of those Particles, which I caused the Painter to view thro' the Microscope, and to draw it as it appears here in *Fig. 5*. A, B, C, D, E.

But pushing on the said Observations farther, and meeting with very few of the same Appearances, I considered whether this Figure might not be purely accidental by its shrinking:

I did also observe, that about the Blood-Vessels which I have already told you, I discovered, as it were shut up under the outmost Membrane, a great many Fat Particles lying; from whence I concluded, that the Woman, who was the Owner thereof, had been very Fat.

I caused some few of those Particles of Fat to be drawn by my Painter, only to show you how those said Particles lie near a Blood-Vessel; they are described by *Fig. 6*. F, G, H, I.

I

When

When we consider the great Protrusion of Blood without the Vessels, as it appeared to our Eyes by the help of a Microscope, we may suppose that such Protrusion or Expulsion of the Blood was occasion'd by a great and sudden Fright or Sorrow, or any other Passion ; from whence we may conclude, that in any such Accidents Bleeding is highly necessary, in order to give the Blood room enough in the Vessels for a free Circulation.

Now if the All-Wise Creator had not covered those Blood-Vessels that lie upon our Bowels, which to our Natural Sight seem, as it were, to lie naked, with a very thin, but a very strong Membrane ; that Blood, which, as is said before, is forced thro' the Veins, would run into the Cavity of the Belly, and there stagnating in great Quantities would rot and putrify, and consequently Death must follow : Whereas now, as it is found to lie in small Parcels on the Bowels and other Places, it may be easily dissolved again ; which, if it were not, it would be the Cause of one's Death, or at least of Sickness : But pardon me, that I have gone thus far beyond my Last.

extract this Substance, and broke some Part of it off, but was forced to dilate the *Rectum*, and so extract it that Way. It was a hard unequal ragged flinty Stone, [see the Figure of it in TAB. IV. at F.] was Ten Inches and an half round, and weighed Eight Ounces and an half, after it was extracted. The Woman has been easy from that Moment; the Wounds, by the Care and Skill of her Chirurgions, are healed; she goes about her Business, has got a good deal of Flesh, and is recovered perfectly, except a Numbness and Contraction she has in some of her Fingers of both Hands, and both Feet and Toes.

J. Mackarness.

IX. *An Account of Mr. Leeuwenhoek's Microscopes; by Mr. Henry Baker, F. R. S.*

HAVING been favoured by this Illustrious SOCIETY with an Opportunity of examining the much-talked-of Microscopes of the famous Mr. *Leeuwenhoek*, who, by his Glasses, made such wonderful Discoveries in the *Minutiæ* of Nature, as have laid the Foundation of a Philosophy unknown to preceding Ages; I think it incumbent on me to shew the Use I have been making of them.

Upon opening the Cabinet that contains these Microscopes, I laid before me an Account of them, drawn up, and presented to this SOCIETY, some Years ago, by its present worthy Vice-President

Martin Folkes, Esq; * and found it such an exact and full Description of their Structure and Uses, as renders any farther Attempt to that Purpose intirely needless. I had likewise the Pleasure to find, that the judicious Observations of this Gentleman, on the Goodness of the Glasses, and the admirable Dexterity of Mr. *Leewwenhoek* in the Management and Application of the Objects fitted to them, had reduced my Task to so narrow a Compass, that little more is left for me to offer than a Calculation of their magnifying Powers, some Reflections arising from such Calculations, and a brief Account of what Improvements in Microscopes have lately been made amongst us.

In order to this, the first thing I went about, was to view attentively the Objects applied to these Microscopes by Mr. *Leewwenhoek* himself, which Mr. *Folkes* has given a List of in his Account; but the greatest Part of them were, I found, destroyed by Time, or struck off by Accident; which indeed is no Wonder, as they were only glewed on a Pin's Point, and left quite unguarded. Nine or Ten of them, however, are still remaining; which, after cleaning the Glasses, appeared extremely plain and distinct, and proved the great Skill of Mr. *Leewwenhoek*, in adapting his Objects to such Magnifiers as would shew them best, as well as in the Contrivance of the Apertures to his Glasses, which, when the Object was transparent, he made exceeding small, since much Light in that Case would be prejudicial: But, when the Object itself was dark, he enlarged the Aperture, to give it

* *Philosophical Transactions*, N^o 380.

all possible Advantage of the Light.—The Lens being set so as to be brought close to the Eye, is also of great Use, since thereby a larger Part of the Object may be seen at one View.

It must be remembered, that all these Microscopes are of one and the same Structure, and that the most simple possible, being only a single Lens, with a moveable Pin before it, on which to fix the Object, and bring it to the Eye at Pleasure.

Though I was sensible it must cost much Trouble to measure the focal Distances of these 26 Microscopes, and thereby ascertain their Powers of magnifying, I considered that, without so doing, it would be impossible to form a right Judgment of them, or make any reasonable Comparison between them and our own. This Task therefore I have performed, with as much Care and Exactness as I was able; and have shewn, in the following Table, how many of them have the same Focus, and consequently magnify in the same Degree; how many times they magnify the Diameter, and how many times the Superficies of any Objects applied to them. I have given the Calculations in round Numbers, the Fractions making but an inconsiderable Difference; and hope any Mistakes I may have made in so nice a Matter will be excused.

A Table of the Focal Distances of Mr. Lceuwenhoek's 26 Microscopes, calculated by an Inch Scale divided into 100 Parts; with a Computation of their magnifying Powers, to an Eye that sees small Objects at 8 Inches, which is the common Standard.

Microscopes with the same Focus.	Distance of the Focus.	Power of magnifying the Diameter of an Object.	Power of magnifying the Superficies.
	<i>Parts of an Inch.</i>	<i>Times.</i>	<i>Times.</i>
* 1.	$\frac{1}{20}$ or $\frac{5}{100}$	160	25600.
1.	$\frac{6}{100}$	133 nearly.	17689.
1.	$\frac{7}{100}$	114 nearly.	12996.
3.	$\frac{8}{100}$	100.	10000.
3.	$\frac{9}{100}$	89 almost.	7921 almost.
8.	$\frac{1}{10}$	80.	6400.
2.	$\frac{11}{100}$	72 something more.	5184 something more.
3.	$\frac{12}{100}$	66 nearly.	4356 nearly.
2.	$\frac{14}{100}$	57	3249.
1.	$\frac{15}{100}$	53 nearly.	2809 nearly.
1.	$\frac{1}{5}$	40.	1600.
<u>26.</u>			

* This largest Magnifier of all is in the Box marked 25.

It appears, by the foregoing Table, that One only of these 26 Microscopes is able to magnify the Diameter of an Object 160, and its Superficies 25600 times; all the rest falling much short of that Degree. And therefore, I am fully persuaded, and believe I shall be able to prove, that many of the Discoveries Mr. *Leeuwenhoek* gives an Account of, could not possibly be made by Glasses that magnify no more than this.

I beg Leave to observe, that our Cabinet is but the Second in Mr. *Leeuwenhoek's* Collection, and is very far from containing all the Microscopes he had, as many wrongly have imagined. We find here indeed, 26 Microscopes in 13 little Boxes: Each Box contains a Couple of them, and is marked in Two Places with a Number, to distinguish it from the rest. But as the first of these Boxes is marked 15, and the rest with following Numbers on to 27; it necessarily implies there were 14 preceding Boxes, since no Man begins with the Number 15.—Mr. *Leeuwenhoek*, then, had another Cabinet, that held 14 Boxes before ours in numerical Order, and probably each Box contained a Couple of Microscopes, as our Boxes do. But, besides these Two Cabinets, he had several other Microscopes of different Sorts, as his own Writings will make appear.

The Cabinet now before us seems to have been only his Repository of Objects; for every Microscope herein was engaged by an Object affixed to it, and thereby rendered useless for any other Purpose; whereas those he employed in his daily Observations must have been always ready, and at full Liberty, to examine whatever offered. Many of them too

must certainly have been much greater Magnifiers than any in our Possession.—And we are assured by himself, that such he had; for he often mentions his shifting Objects from his common to his better, and thence to his most exquisite Microscopes: And, besides, (in the Second Volume of his Works, Part II. pag. 290.) he says, “ *Mihi quidem sunt centum* “ *centumque Microscopia, &c.* “ I have an hundred “ and an hundred Microscopes, most whereof are “ able to shew Objects so distinctly, even in the “ cloudiest Weather, and by Day-light only, that if “ the *Animalcula in Semine masculino* of Animals “ had the Extremity of their Tails forked, (as described by a certain Writer) I should easily have “ discovered it.”—Among this Number, many, without doubt, were contrived for the Examination of Fluids, since great Part of his Observations were made on them: He informs us also, that his Method was to put them into an exceeding small or capillary Tube of Glass, which there does not seem to be any Means of applying to the Microscopes in our Cabinet, even had they been at Liberty; and much less for the larger Tubes he made use of to view the Circulation of the Blood in *Frogs, Eels, Fishes, &c.* his Apparatus for which we find in the Fourth Volume of his Works, pag. 180.—But to proceed:

Mr. *Leeuwenhoek*, in a Letter to this SOCIETY concerning the *Animalcula* observed by him in the *Semen masculinum* of a *Dog*, which he describes and gives a Draught of, says, they were so minute, that he believed a Million of them would not equal the Size of One large Grain of Sand. Vol. I. Part I. pag. 160. Again, in his 113th Letter, speaking of the

Semen virile, he declares, that a Million of the *Animalcula* seen therein would not equal a large Grain of Sand; and yet he gives a full Description of their Form; for he says, their Bodies are roundish, somewhat flat before, but ending sharp behind, with Tails exceedingly transparent, Five or Six times longer, and about Five times slenderer, than their Bodies; so that their Figure cannot better be represented, than by a small *Earth-nut* with a long Root or Tail.

Now the Focus of the greatest Magnifier of his being $\frac{1}{20}$ of an Inch, as near as can well be measured, it is capable of magnifying the Diameter of an Object (to an Eye that sees small Objects best at Eight Inches) no more than 160, and the Superficies 25600 times: So that Objects, One Million whereof scarce equal a Grain of Sand, viewed through such a Lens, (as only the Superficies can be seen) could appear no larger than Two Grains and half of Sand would be to the naked Eye; and I submit it to be considered, whether that is not too small a Size for any Man to describe so particularly, and delineate the Form and Parts of.

But Mr. *Leewwenhoek* goes yet abundantly farther: For, to mention only one Instance, of which there are several in his Writings; he tells this SOCIETY in his Letter of *July 25. 1684.* that he could discern Vessels in the human Eye, so amazingly minute, that, desiring to know their Smallness, he measured them by the Diameter of a Grain of Sand, (the Process of which Mensuration is there set down) and found by arithmetical Calculation, that a large Grain of Sand

must be divided into * Eighteen thousand Three hundred Ninety-nine Millions Seven hundred Forty-four thousand Parts, ere it can be small enough to enter these minute Vessels.—What shall we now say?—Why, in regard to the Memory of this great Man, to whom the World, and this SOCIETY, are much obliged, I must insist, that he certainly had Glasses, that were much greater Magnifiers than any we have of his.

It may perhaps be objected, that Mr. *Leeuwenhoek* declares, he did not use such small Glasses as some People boasted of; and that, although for 40 Years together he had been possessed of Glasses exceedingly minute, he had employed them very seldom; since, in his Opinion, they could not so well serve to make the first Discoveries of Things, as those of a larger Diameter. In Answer to this, I must beg Leave to observe, that Mr. *Leeuwenhoek*, in this Place, is reflecting on a certain Physician, who boasted of an extraordinary † Microscope scarce bigger than a visible Point, whereby he pretended to discover the *Animalcules in Semine virili* to be exactly of an human Shape, with only a Skin over it. For he says, that while he was attentively observing these *Animalcules*, one of them (a little bigger than the rest) presented itself, having almost slipped off its Skin: And then there plainly appeared Two naked Thighs and Legs, a Breast, and Two Arms, above which, the Skin being thrust up, covered the Head as it were a Cap.

* Vol. I. p. 39.

† Epist. 116. Vol. II. Part II. pag. 84.

The Sex he confesses he could not distinguish, and adds, that it died in endeavouring to get clear of the Skin.

Mr. *Leeuwenhoek* very justly exposes this romantic Discovery, pretended to be made by this Speck of a Microscope; and takes occasion therefrom to let us know, he does not think such minute Glasses are so much to be depended on as those of a larger Diameter. But there are so many Degrees between the smallest Glass we have of his, (whose Focus is at $\frac{1}{10}$ of an Inch) and this almost invisible Point, that we must not infer from hence he used none of a Size between. Nay, this very Letter seems to imply the contrary; for it tells us, that, in examining the *Semen virile*, he made use of Eight or Ten Microscopes of different magnifying Powers: But as all the Microscopes we have of his, have Objects fastened to them, and besides have no Apparatus for Fluids, I think they could not probably be the same he employed for that Examination. May we not rather suppose he had Eight or Ten different Sizes of Microscopes, that magnified more than ours? For we know, Fluids require to be examined by the greatest Magnifiers; and doubtless he made use of such for that Purpose.

There is no Advantage in employing a greater Magnifier for any Object, than what is requisite to shew the same distinctly; but when the Object is exceedingly minute, the magnifying Power of the Glass must be proportionably great, or else it will be impossible to see the Object clearly. A Lens, (for Example) that shews a whole *Flea* distinctly, mag-

nifies not near enough to shew the *Animalcules* in the *Semen* of that *Flea*.

I am sensible, that Mr. *Leewwenhoek*, by long Practice, and uncommon Attention, might be able to discern many Objects with these Microscopes, which others, less accustomed to Observations of this kind, cannot readily do: His Eyes too might be somewhat different from the Standard I measure by. But all these Allowances will not, I think, suffice to reconcile the Passages I have quoted with the Powers of the Glasses under Examination.

While I was overlooking these Microscopes of Mr. *Leewwenhoek*, an Opportunity presented of examining and comparing with them a curious Apparatus of Silver with Six different Magnifiers, belonging to Mr. *Folkes*, and then newly made for him by Mr. *Cuff*, in *Fleetstreet*.—The Body of this Instrument, into which the Glasses are occasionally to be fastened, is after the Fashion of *Wilson's* Pocket Microscope, and contrived to screw into the Side of a Scroll fixed on a Pedestal, from which a turning *Speculum* reflects the Light upwards upon the Object: It is likewise contrived to be used with the Apparatus of the Solar Microscope: Descriptions and Figures of both of which I have since given in a Book intituled, *The Microscope made easy*. Edit. 2^d. Lond. 1743. 8^o.

I measured the focal Distances, and magnifying Powers, of the Six Glasses, and found them to be as follows:

A Table of the Six Magnifiers belonging to Mr. Folkes's Microscope, calculated by an Inch Scale divided into an hundred Parts, with a Computation of their Powers, to an Eye that sees Objects at Eight Inches.

Glas- ses.	Distance of the Focus.	Magnifies the Diameter.	Magnifies the Superficies.
1ft.	. . $\frac{1}{50}$ of an Inch.	. . 400.	. . 160,000.
2d.	. . $\frac{1}{20}$	. . 160.	. . 25,600.
3d.	. . $\frac{8}{100}$	. . 100.	. . 10,000.
4th.	. . $\frac{18}{100}$	. . 44.	. . 1,936.
5th.	. . $\frac{3}{10}$	. . 26.	. . 676.
6th.	. . $\frac{1}{2}$	. . 16.	. . 256.

The above Calculation shews, that Mr. *Folkes's* First Glass magnifies the Superficies of an Object Six times as much as the greatest Magnifier of Mr. *Leeuwenhoek*: And that the *Animalcula* (a Million whereof, he says, scarce equalled the Bigness of a Grain of Sand) would, if viewed with this Magnifier, appear as large as Sixteen Grains of Sand do to the naked Eye. And I cannot suppose but Mr. *Leeuwenhoek* had Glasses to magnify even more than this, though they are not come to us. For I cannot otherwise conceive, how he could observe the *Animalcules* in the *Semen masculinum* of a *Flea*, and of a *Gnat*, as we find he did, (Vol. IV. pag. 21, 22.) or assert, as he does in the strongest Terms, (pag. 23.) that he could see the minutest Sort of *Animalcules* in *Pepper-water*, with his Glasses, as plainly as he could Swarms of *Flies* or *Gnats* hovering in the Air with

U u u

his

his naked Eye, though they were more than Ten Millions of Times less than a Grain of Sand.—And lest this should be imagined only a random Guess, he gives immediately a regular Arithmetical Calculation to prove his Computation right. But I believe we must all be sensible, that no Glasses in this Cabinet are able to render such minute Objects distinguishable.

I am desirous to do all possible Justice to these Microscopes, by acknowledging their Excellence, as far as their magnifying Power extends: But I should do Wrong to Mr. *Leeuwenhoek*, should I suffer the World to believe these were his greatest Magnifiers; since whoever hereafter should examine them with that Imagination, would be apt to entertain a bad Opinion of his Veracity.

Experience teaches, that Globules of Glass extremely minute, though they magnify prodigiously, are seldom able to shew Objects sufficiently distinct, and therefore are very apt to lead People into Errors: Which certainly was a good Reason for Mr. *Leeuwenhoek's* rejecting them: But a ground convex *Lens*, though much smaller than any of his before us, if rightly applied, will shew exceedingly minute Objects magnified to a surprising Degree, and with sufficient Light and Clearness, as Mr. *Folkes's* First Glass witnesses.

I hope I shall not be imagined to intend any Disrespect to this famous Man, if I suppose, that our present Microscopes are much more useful and convenient than these of his. Let him always be remembered with the highest Honour, for the wonderful Discoveries he made, and the Microscopes he

has left us, which are indeed extraordinary, when considered as the First almost of their Kind: Let us reverence him as our great Master in this Art. But the World since must have been strangely stupid, if it could have improved nothing, where there was room for so much Improvement. I do not mean as to the Glasses (for the Goodness of these before us, gives just Reason to believe he might have others as excellent as can perhaps be ever made); but as to the Structure of the Instrument they are set in, and the Manner of applying Objects to them. And I fancy most People will allow, that herein great Improvements have been made: And it is with Pleasure I find, that a large Share of the Credit belongs to our own Countrymen.

One thing alone (which, when slightly considered, may appear but trifling) has conduced greatly to these Improvements; and that is, the making use of fine transparent *Muscovy Talc* or *Isinglass*, placed in Sliders, to inclose Objects in. Had Mr. *Leeuwenhoek* known this Way, it would have saved him a vast deal of Expence and Trouble: For then, we may reasonably suppose, instead of making an intire and separate Microscope for every Object he was desirous to keep by him in Readiness to shew his Friends, he would probably have secured his Objects in Sliders, as we at present do, and have contrived some such Means as ours, of screwing his several Glasses of different magnifying Powers, occasionally, to one and the same Instrument, and of applying his Sliders to which of them he judged best.—A few good Glasses, gradually magnifying one more than other, would, by such a Method, have answered all the

Purposes of his great Number, and his Objects would have been preserved in a much better Manner.

I shall forbear troubling you with the different Microscopes invented by *Wilson, Marshall, Culpeper, Scarlet*, and others, (though all deserving Praise) since you are already so well acquainted with them: But Two extraordinary Improvements have appeared within these Two Years, which I beg Leave to lay before you, as I think it has not been yet done.— I mean, the Solar or *Camera Obscura* Microscope, and the Microscope for opake Objects. Both these Inventions we are obliged for to the ingenious Dr. *Liberkhun*, who, when he was in *England* last Winter was Twelvemonth, shewed an Apparatus of his own making, for each of these Purposes, to several Gentlemen of this SOCIETY, as well as to some Opticians, amongst whom Mr. *Cuff*, in *Fleetstreet*, has taken great Pains to improve and bring them to Perfection; and therefore the Apparatus prepared by him is what I am about to describe.

This Solar Microscope is composed of a Tube, a Looking-glass, a convex Lens, and a Microscope. The Tube is of Brass, near Two Inches in Diameter, fixed in a circular Collar of *Mahogany*, which, turning round at Pleasure, in a square Frame, may be adjusted easily to a Hole in the Shutter of a Window, in such a Manner, that no Light can pass into the Room but through the aforesaid Tube. Fastened to the Frame by Hinges, on the Side that goes without the Window, is a Looking-glass, which, by means of a jointed brass Wire coming through the Frame, may be moved either vertically or horizontally, to throw the Sun's Rays through the brass Tube into the darkened Room.

Room. The End of the brass Tube without the Shutter has a convex Lens, to collect the Rays, and bring them to a Focus; and on the End within the Room, *Wilson's* Pocket-Microscope is screwed, with the Object to be examined applied to it in a Slider. The Sun's Rays being directed by the Looking-glass through the Tube upon the Object, the Image or Picture of the Object is thrown distinctly and beautifully upon a Screen of white Paper, and may be magnified beyond the Imagination of those who have not seen it.—I assisted lately in making some Experiments with Dr. *Alexander Stuart*, by means of this Instrument, and a particular Apparatus contrived, by him, for viewing the Circulation of the Blood in *Frogs, Mice, &c.* and had the Pleasure of beholding the Veins and Arteries in the Mesentery of a *Frog* magnified to near Two Inches Diameter, with the Globules of the Blood rolling through them as large almost as *Pepper-corns*. We examined also the Structure of the Muscles of the *Abdomen*, which were prodigiously magnified, and exhibited a most delightful Picture. But, as the Doctor intends himself to communicate to you an Account of these Experiments, I will not anticipate your Pleasure.

The Microscope for opaque Objects remedies the Inconvenience of having the dark Side of an Object next the Eye: For by means of a concave Speculum of Silver, highly polished, in whose Centre a magnifying Lens is placed, the Object is so strongly illuminated, that it may be examined with all imaginable Ease and Pleasure.—A convenient Apparatus of this kind, with Four different Specula, and Magnifiers of different Powers, has lately been brought

to Perfection by Mr. *Cuff*; whose Copper-plate and Description of it, as it will save much Trouble, and make me better understood, I take the Liberty, at his Desire, to present herewith, together with his printed Account of the Solar Microscope, the Pocket Microscope, and the Microscope before spoken of, with a Scroll, Pedestal, and Speculum, of which there are also Copper Plates. These, with the large double reflecting Microscope, are, I think, the chief, if not the only useful Sorts now made in *England*.

I must not omit taking notice, that Mr. *Leeuwenhoek* says, (in his Second Volume, Part II. pag. 93.) that sometimes, to throw a greater Light upon his Objects, he used a small convex Metal Speculum. How he applied it, I will not pretend to guess; but it is highly probable our double reflecting Microscope may be owing to this Hint. I must also observe farther, that in the Fourth Volume of his Works, pag. 182. after describing his Apparatus for viewing *Eels* in glass Tubes, Mr. *Leeuwenhoek* adds, that he had another Instrument, whereto he screwed a Microscope set in Brass; upon which Microscope, he tells us, he fastened a little Dish (of Brass also, I suppose), that his Eye might be thereby assisted to see Objects better: For he says, he had filed the Brass which was round his Microscope, as bright as he could, that the Light, while he was viewing Objects, might be reflected from it as much as possible. This Microscope, with its Dish, (which I give an exact Copy of from the Picture in his Works) seems so like our opaque Microscope with its silver Speculum, that, after considering his own Words, I submit to your better Judgment, whether he is not properly
the

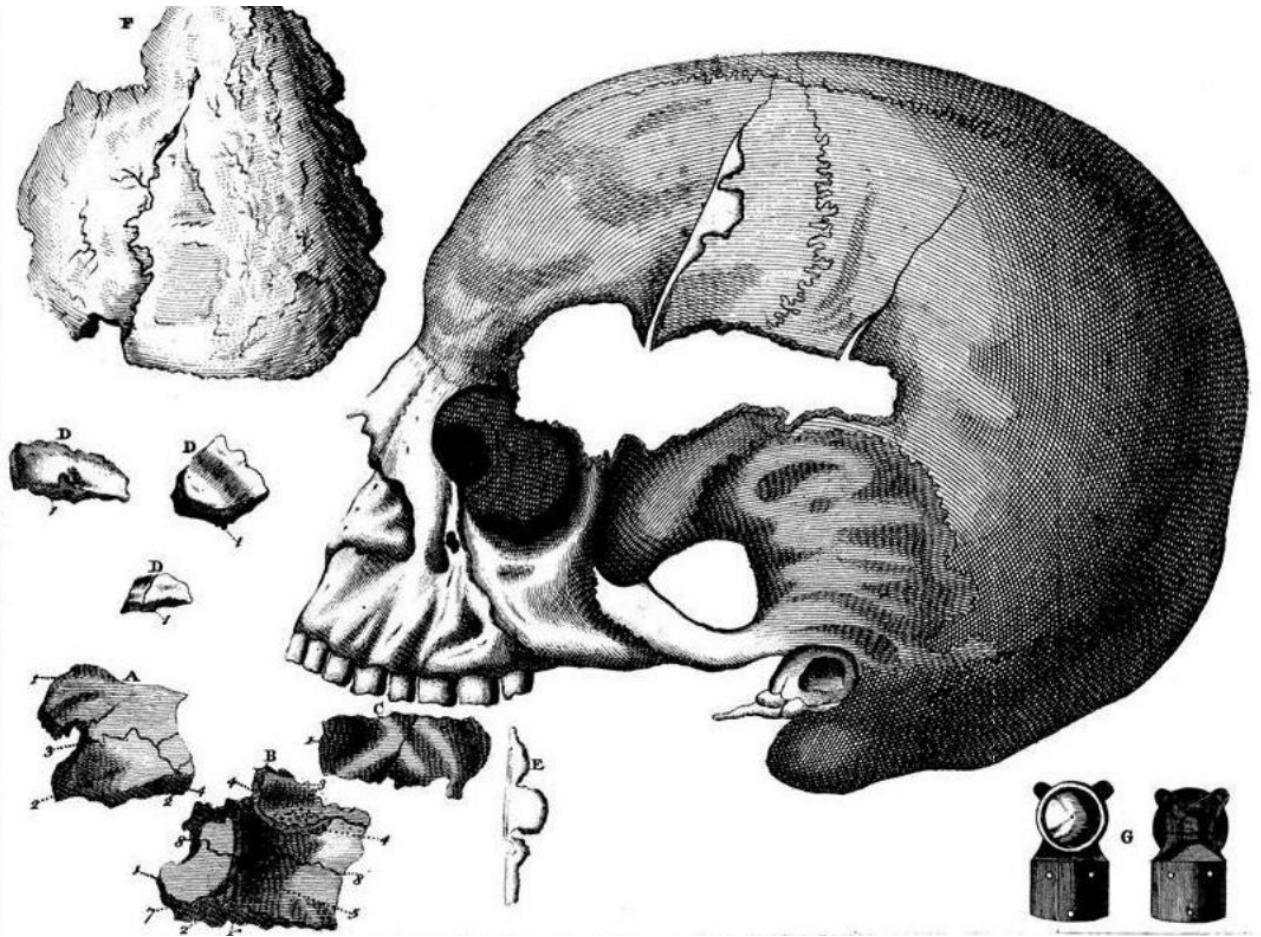
the Inventor of it. His Words are these,—“ Supra
 “ hoc Microscopium Catillum ferruminavi, ut oculus
 “ objecta tanto melius videret: nam cuprum circa
 “ Microscopium, quantum pote, lima abraferam, ut
 “ Lumen in conspicienda objecta, quantum pote,
 “ irradiaret.”

See the Figure of this Apparatus in TAB. IV. at G.

X. *An Inquiry into the Causes of a dry and
 wet Summer. By an anonymous Hand.*

THE wet Weather which we had in *March*
 1734. (the Year beginning with *January*) set
 me on considering what might be the Causes of it.
 The Wind was then, generally, South-west, the
 Weather rainy. Sometimes it veered to South-east,
 which, commonly, brought much Rain: But the
 Wind seldom stood at that Point 24 Hours, before it
 returned to South-west again. A strong Gale at
 South-west, with Rain, would be succeeded by as
 strong at North-west, still raining; but if the North-
 west continued 24 Hours, it cleared the Sky. The
 Summer following was cold and wet; the Wind on
 the same Points. The preceding Winter was mild,
 and especially *December*, in which Month, from the
 10th inclusive, the Wind blew, generally, South-west,
 sometimes strong, attended with much Rain. At
 the End of *December*, the Birds sang, and the Grass
 did grow as at other Years in the Spring.

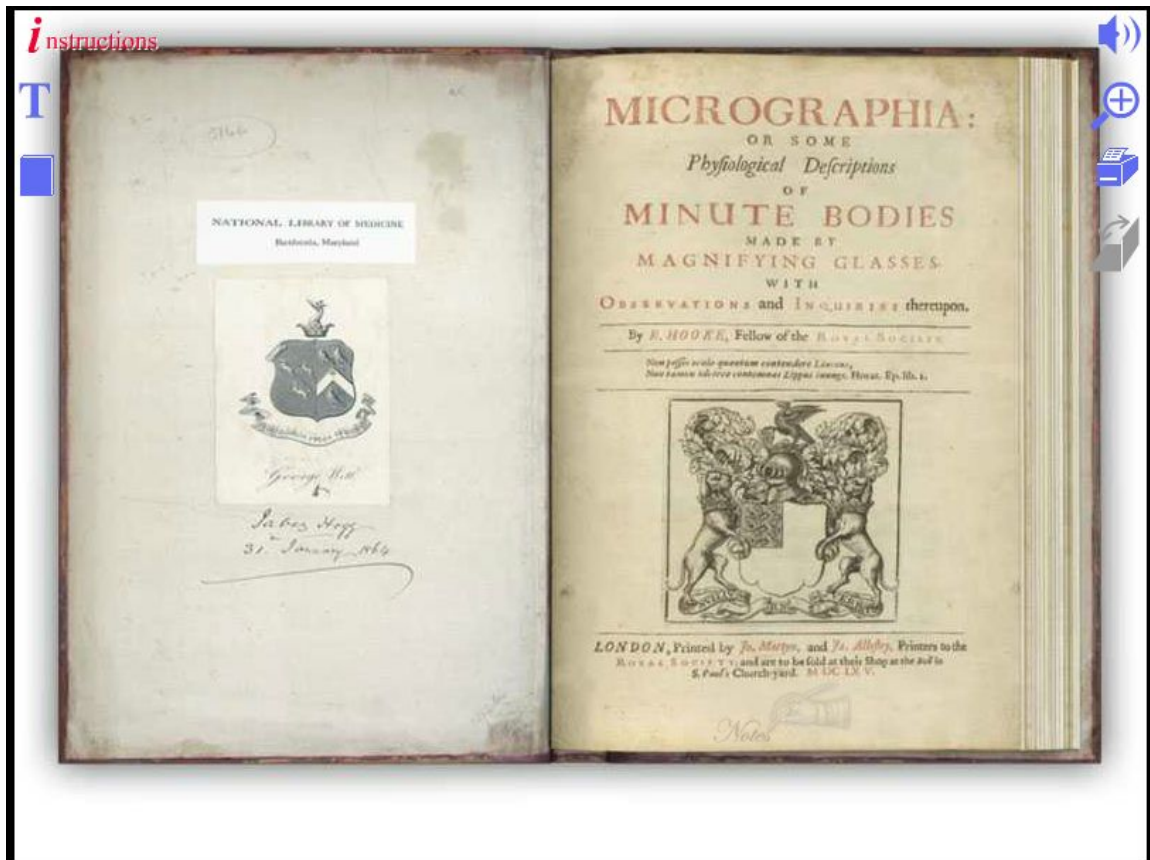
The Winter of 1734. was as mild as that of 1733.
 the Birds as joyful, and the Grass as green at the End
 of

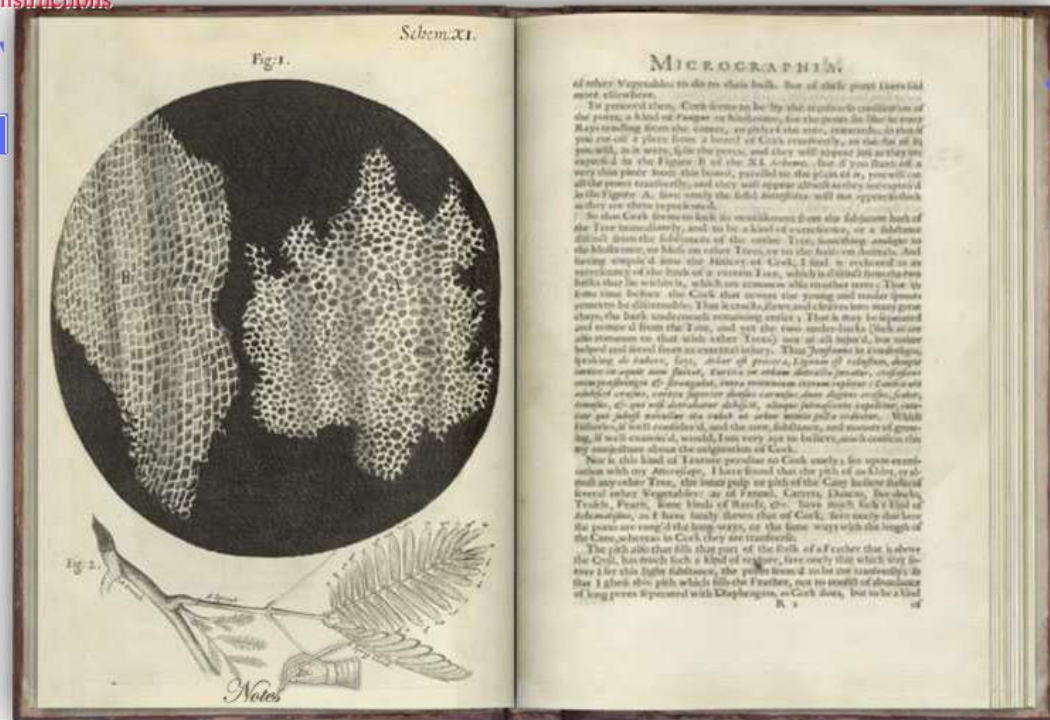


9. Appendix III.

I. Micrographia Interactive E book

The following inserts are from an interactive copy of Micrographia. This will allow students to virtually turn pages and observe drawings from the original copy of Micrographia by Robert Hooke. It can be accessed on: <http://archive.nlm.nih.gov/proj/ttp/flash/hooke/hooke.html>





10. Appendix IV.

I. Extra Materials for the Miller-Urey Experiment

The unit for the Miller-Urey Project was not fully designed however an important historical document is included below to be used in the course. This will provide students the chance to experience science and how it was perceived in the 1950s before DNA was thought to be the genetic material.

The document below is a journal article is the original publication by Stanley Miller on his famous experiment (Miller, 1953). This can be accessed for free on [jstor.com](https://www.jstor.org/stable/2418682).



A Production of Amino Acids under Possible Primitive Earth Conditions

Stanley L. Miller

Science, New Series, Volume 117, Issue 3046 (May 15, 1953), 528-529.

Stable URL:

<http://links.jstor.org/sici?sici=0036-8075%2819530515%293%3A117%3A3046%3C528%3AAPOAAU%3E2.0.CO%3B2-9>

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ties of the compounds manometrically (5). In the other, the material is applied to the paper along 8 cm of the base line rather than as a spot and, after resolution, areas 8 x 5 cm containing the various compounds are cut from the paper and rolled in shell vials. Ten anesthetized houseflies are then introduced into each vial, and the toxicity of the compounds is characterized by rate of knockdown and 24-hr mortality.

The paper chromatographic method is useful in studying the metabolism of phosphorus insecticides in plants, mammals, and insects. With it, for example, we have been able to demonstrate the conversion of parathion and its methyl analog to the corresponding phosphates by an enzyme system found in *Periplaneta americana* (L.) (2). Further studies are in progress. The method has also been of value in studying the action of heat on purified parathion and methyl parathion and in isolating the compounds formed and in studying their biological properties (1).

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Manuscript received September 15, 1952.

A Production of Amino Acids Under Possible Primitive Earth Conditions

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The idea that the organic compounds that serve as the basis of life were formed when the earth had an atmosphere of methane, ammonia, water, and hydrogen instead of carbon dioxide, nitrogen, oxygen, and water was suggested by Oparin (1) and has been given emphasis recently by Urey (2) and Bernal (3).

In order to test this hypothesis, an apparatus was built to circulate CH_4 , NH_3 , H_2O , and H_2 past an electric discharge. The resulting mixture has been tested for amino acids by paper chromatography. Electrical discharge was used to form free radicals instead of ultraviolet light, because quartz absorbs wavelengths short enough to cause photo-dissociation of the gases. Electrical discharge may have played a significant role in the formation of compounds in the primitive atmosphere.

The apparatus used is shown in Fig. 1. Water is boiled in the flask, mixes with the gases in the 5-l flask, circulates past the electrodes, condenses and empties back into the boiling flask. The U-tube prevents circulation in the opposite direction. The acids

¹ National Science Foundation Fellow, 1952-53.

² Thanks are due Harold C. Urey for many helpful suggestions and guidance in the course of this investigation.

and amino acids formed in the discharge, not being volatile, accumulate in the water phase. The circulation of the gases is quite slow, but this seems to be an asset, because production was less in a different apparatus with an aspirator arrangement to promote circulation. The discharge, a small corona, was provided by an induction coil designed for detection of leaks in vacuum apparatus.

The experimental procedure was to seal off the opening in the boiling flask after adding 300 ml of water, evacuate the air, add 10 cm pressure of H_2 , 20 cm of CH_4 , and 20 cm of NH_3 . The water in the flask was boiled, and the discharge was run continuously for a week.

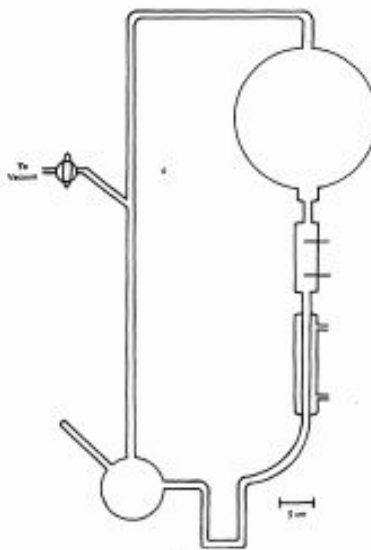


FIG. 1.

During the run the water in the flask became noticeably pink after the first day, and by the end of the week the solution was deep red and turbid. Most of the turbidity was due to colloidal silicas from the glass. The red color is due to organic compounds adsorbed on the silicas. Also present are yellow organic compounds, of which only a small fraction can be extracted with ether, and which form a continuous streak tapering off at the bottom on a one-dimensional chromatogram run in butanol-acetic acid. These substances are being investigated further.

At the end of the run the solution in the boiling flask was removed and 1 ml of saturated HgCl_2 was added to prevent the growth of living organisms. The ampholytes were separated from the rest of the constituents by adding $\text{Ba}(\text{OH})_2$ and evaporating *in vacuo* to remove amines, adding H_2SO_4 and evaporat-

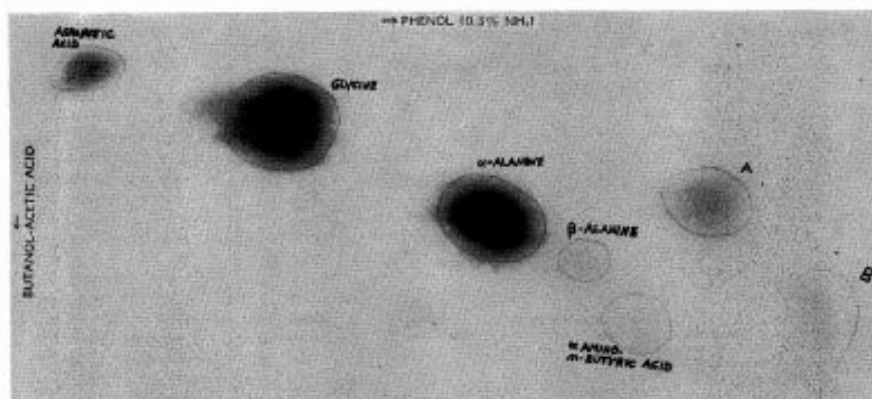


FIG. 2.

ing to remove the acids, neutralizing with $\text{Ba}(\text{OH})_2$, filtering and concentrating *in vacuo*.

The amino acids are not due to living organisms because their growth would be prevented by the boiling water during the run, and by the HgCl_2 , $\text{Ba}(\text{OH})_2$, H_2SO_4 , during the analysis.

In Fig. 2 is shown a paper chromatogram run in *n*-butanol-acetic acid-water mixture followed by water-saturated phenol, and spraying with ninhydrin. Identification of an amino acid was made when the R_f value (the ratio of the distance traveled by the amino acid to the distance traveled by the solvent front), the shape, and the color of the spot were the same on a known, unknown, and mixture of the known and unknown; and when consistent results were obtained with chromatograms using phenol and 77% ethanol.

On this basis glycine, α -alanine and β -alanine are identified. The identification of the aspartic acid and α -amino-*n*-butyric acid is less certain because the spots are quite weak. The spots marked A and B are unidentified as yet, but may be beta and gamma amino acids. These are the main amino acids present, and others are undoubtedly present but in smaller amounts. It is estimated that the total yield of amino acids was in the milligram range.

In this apparatus an attempt was made to duplicate a primitive atmosphere of the earth, and not to obtain the optimum conditions for the formation of amino acids. Although in this case the total yield was small for the energy expended, it is possible that, with more efficient apparatus (such as mixing of the free radicals in a flow system, use of higher hydrocarbons from natural gas or petroleum, carbon dioxide, etc., and optimum ratios of gases), this type of process would be a way of commercially producing amino acids.

A more complete analysis of the amino acids and other products of the discharge is now being performed and will be reported in detail shortly.

May 15, 1953

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A Vacuum Microsublimation Apparatus

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The analytical biochemist is frequently confronted with the task of isolating microquantities of substances in a chemically pure state from small quantities of tissues or biological fluids. Kofler (1) edited a book covering the use of microsublimation, melting point, eutectics, etc., in identifying microquantities of organic material. The advantages of sublimation over other methods of purification have been discussed by Hubacher (2). Many types of vacuum sublimation apparatus have been described (2-3). The equipment described here is inexpensive and can be assembled readily by any laboratory worker with a modicum of glassblowing skill.

To a thick-walled, round-bottom, Pyrex test tube, 30 x 200 mm., is attached a glass side arm about one in. from the bottom. Using a suspension of very fine emery in glycerin or fine valve-grinding compound, the open end of the test tube is ground against the aluminum block of a Fisher-Johns melting point apparatus (Fisher Scientific Co., St. Louis, Mo.) until it makes a vacuum-tight seal when dry. This is the vacuum hood. Microbeakers are prepared from flat-

¹ The author is indebted to Robert Pickett, of this laboratory, for technical assistance in preparing this apparatus.

529

Another important document for the Miller-Urey experiment is a journal article entitled Origin of Life by George Wald for the Scientific American published in 1954. This article importantly unites religious concepts with the newly emerging ideas about evolution and the scientific research about life. This article was written to describe Miller's experiment which was published in 1953 prior to establishing that DNA was the genetic material. It offers important historical insights from the scientific research boom in the 1950s: a time where concepts and ideas of thought were drastically changing. The article is included below.



BIBLICAL ACCOUNT of the origin of life is part of the Creation, here illustrated in a 16th-century Bible printed in Lyons. On the first day (*die primo*) God created heaven and the earth. On the second day (*die secundo*) He separated the firmament and the waters. On the third day (*die tertio*) He made the dry land and plants. On the fourth day (*die quarto*) He made the sun, the moon

and the stars. On the fifth day (*die quinto*) He made the birds and the fishes. On the sixth day (*die sexto*) He made the land animals and man. In this account there is no theological conflict with spontaneous generation. According to Genesis God, rather than creating the animals and plants directly, bade the earth and waters bring them forth. One theological view is that they retain this capacity.

THE ORIGIN OF LIFE

How did living matter first arise on the earth? As natural scientists learn more about nature they are returning to a hypothesis their predecessors gave up almost a century ago: spontaneous generation

by George Wald

About a century ago the question, How did life begin?, which has interested men throughout their history, reached an impasse. Up to that time two answers had been offered: one that life had been created supernaturally, the other that it arises continually from the nonliving. The first explanation lay outside science; the second was now shown to be untenable. For a time scientists felt some discomfort in having no answer at all. Then they stopped asking the question.

Recently ways have been found again to consider the origin of life as a scientific problem—as an event within the order of nature. In part this is the result of new information. But a theory never rises of itself, however rich and secure the facts. It is an act of creation. Our present ideas in this realm were first brought together in a clear and defensible argument by the Russian biochemist A. I. Oparin in a book called *The Origin of Life*, published in 1936. Much can be added now to Oparin's discussion, yet it provides the foundation upon which all of us who are interested in this subject have built.

The attempt to understand how life originated raises a wide variety of scientific questions, which lead in many and diverse directions and should end by casting light into many obscure corners. At the center of the enterprise lies the hope not only of explaining a great past event—important as that should be—but of showing that the explanation is workable. If we can indeed come to understand how a living organism arises from the nonliving, we should be able to construct one—only of the simplest description, to be sure, but still recognizably alive. This is so remote a possibility now

that one scarcely dares to acknowledge it; but it is there nevertheless.

One answer to the problem of how life originated is that it was created. This is an understandable confusion of nature with technology. Men are used to making things; it is a ready thought that those things not made by men were made by a superhuman being. Most of the cultures we know contain mythical accounts of a supernatural creation of life. Our own tradition provides such an account in the opening chapters of Genesis. There we are told that beginning on the third day of the Creation, God brought forth living creatures—first plants, then fishes and birds, then land animals and finally man.

Spontaneous Generation

The more rational elements of society, however, tended to take a more naturalistic view of the matter. One had only to accept the evidence of one's senses to know that life arises regularly from the nonliving: worms from mud, maggots from decaying meat, mice from refuse of various kinds. This is the view that came to be called spontaneous generation. Few scientists doubted it. Aristotle, Newton, William Harvey, Descartes, van Helmont, all accepted spontaneous generation without serious question. Indeed, even the theologians—witness the English Jesuit John Turberville Needham—could subscribe to this view, for Genesis tells us, not that God created plants and most animals directly, but that He bade the earth and waters to bring them forth; since this directive was never rescinded, there is nothing heretical in believing that the process has continued.

But step by step, in a great controversy that spread over two centuries, this belief was whittled away until nothing remained of it. First the Italian Francesco Redi showed in the 17th century that meat placed under a screen, so that flies cannot lay their eggs on it, never develops maggots. Then in the following century the Italian abbé Lazzaro Spallanzani showed that a nutritive broth, sealed off from the air while boiling, never develops microorganisms, and hence never rots. Needham objected that by too much boiling Spallanzani had rendered the broth, and still more the air above it, incompatible with life. Spallanzani could defend his broth; when he broke the seal of his flasks, allowing new air to rush in, the broth promptly began to rot. He could find no way, however, to show that the air in the sealed flask had not been vitiated. This problem finally was solved by Louis Pasteur in 1860, with a simple modification of Spallanzani's experiment. Pasteur too used a flask containing boiling broth, but instead of sealing off the neck he drew it out in a long, S-shaped curve with its end open to the air. While molecules of air could pass back and forth freely, the heavier particles of dust, bacteria and molds in the atmosphere were trapped on the walls of the curved neck and only rarely reached the broth. In such a flask the broth seldom was contaminated; usually it remained clear and sterile indefinitely.

This was only one of Pasteur's experiments. It is no easy matter to deal with so deeply ingrained and common-sense a belief as that in spontaneous generation. One can ask for nothing better in such a pass than a noisy and stubborn opponent, and this Pasteur had in the

45

naturalist Félix Pouchet, whose arguments before the French Academy of Sciences drove Pasteur to more and more rigorous experiments. When he had finished, nothing remained of the belief in spontaneous generation.

We tell this story to beginning students of biology as though it represents a triumph of reason over mysticism. In fact it is very nearly the opposite. The reasonable view was to believe in spontaneous generation; the only alternative, to believe in a single, primary act of supernatural creation. There is no third position. For this reason many scientists a century ago chose to regard the belief in spontaneous generation as a "philosophical necessity." It is a symptom of the philosophical poverty of our time that this necessity is no longer appreciated. Most modern biologists, having reviewed with satisfaction the downfall of the spontaneous generation hypothesis, yet unwilling to accept the alternative belief in special creation, are left with nothing.

I think a scientist has no choice but to approach the origin of life through a hypothesis of spontaneous generation. What the controversy reviewed above showed to be untenable is only the belief that living organisms arise spontaneously under present conditions. We have now to face a somewhat different problem: how organisms may have arisen spontaneously under different conditions in some former period, granted that they do so no longer.

The Task

To make an organism demands the right substances in the right proportions and in the right arrangement. We do not think that anything more is needed—but that is problem enough.

The substances are water, certain salts—as it happens, those found in the ocean—and carbon compounds. The latter are called *organic* compounds because they scarcely occur except as products of living organisms.

Organic compounds consist for the most part of four types of atoms: carbon, oxygen, nitrogen and hydrogen. These four atoms together constitute about 99 per cent of living material, for hydrogen and oxygen also form water. The organic compounds found in organisms fall mainly into four great classes: carbohydrates, fats, proteins and nucleic acids. The illustrations on this and the next three pages give some notion of their composition and degrees of complexity. The fats are simplest, each consisting of three fatty acids joined to glycerol. The starches and glycogens are made of sugar units strung together to form long straight and branched chains. In general only one type of sugar appears in a single starch or glycogen; these molecules are large, but still relatively simple. The principal function of carbohydrates and fats in the organism is to serve as fuel—as a source of energy.

The nucleic acids introduce a further level of complexity. They are very large structures, composed of aggregates of at least four types of unit—the nucleotides—brought together in a great variety of proportions and sequences. An almost endless variety of different nucleic acids is possible, and specific differences among them are believed to be of the highest importance. Indeed, these structures are thought by many to be the main constituents of the genes, the bearers of hereditary constitution.

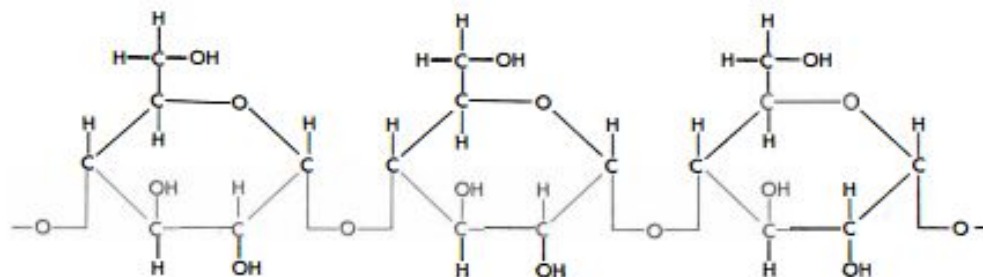
Variety and specificity, however, are most characteristic of the proteins, which include the largest and most complex molecules known. The units of

which their structure is built are about 25 different amino acids. These are strung together in chains hundreds to thousands of units long, in different proportions, in all types of sequence, and with the greatest variety of branching and folding. A virtually infinite number of different proteins is possible. Organisms seem to exploit this potentiality, for no two species of living organism, animal or plant, possess the same proteins.

Organic molecules therefore form a large and formidable array, endless in variety and of the most bewildering complexity. One cannot think of having organisms without them. This is precisely the trouble, for to understand how organisms originated we must first of all explain how such complicated molecules could come into being. And that is only the beginning. To make an organism requires not only a tremendous variety of these substances, in adequate amounts and proper proportions, but also just the right arrangement of them. Structure here is as important as composition—and what a complication of structure! The most complex machine man has devised—say an electronic brain—is child's play compared with the simplest of living organisms. The especially trying thing is that complexity here involves such small dimensions. It is on the molecular level; it consists of a detailed fitting of molecule to molecule such as no chemist can attempt.

The Possible and Impossible

One has only to contemplate the magnitude of this task to concede that the spontaneous generation of a living organism is impossible. Yet here we are—as a result, I believe, of spontaneous generation. It will help to digress for a mo-



CARBOHYDRATES comprise one of the four principal kinds of carbon compound found in living matter. This structural formula

represents part of a characteristic carbohydrate. It is a polysaccharide consisting of six-carbon sugar units, three of which are shown.

ment to ask what one means by "impossible."

With every event one can associate a probability—the chance that it will occur. This is always a fraction, the proportion of times the event occurs in a large number of trials. Sometimes the probability is apparent even without trial. A coin has two faces; the probability of tossing a head is therefore 1/2. A die has six faces; the probability of throwing a deuce is 1/6. When one has no means of estimating the probability beforehand, it must be determined by counting the fraction of successes in a large number of trials.

Our everyday concept of what is impossible, possible or certain derives from our experience: the number of trials that may be encompassed within the space of a human lifetime, or at most within recorded human history. In this colloquial, practical sense I concede the spontaneous origin of life to be "impossible." It is impossible as we judge events in the scale of human experience.

We shall see that this is not a very meaningful concession. For one thing, the time with which our problem is concerned is geological time, and the whole extent of human history is trivial in the balance. We shall have more to say of this later.

But even within the bounds of our own time there is a serious flaw in our judgment of what is possible. It sounds impressive to say that an event has never been observed in the whole of human history. We should tend to regard such an event as at least "practically" impossible, whatever probability is assigned to it on abstract grounds. When we look a little further into such a statement, however, it proves to be almost meaningless. For men are apt to reject reports of very improbable occurrences. Persons of good

judgment think it safer to distrust the alleged observer of such an event than to believe him. The result is that events which are merely very extraordinary acquire the reputation of never having occurred at all. Thus the highly improbable is made to appear impossible.

To give an example: Every physicist knows that there is a very small probability, which is easily computed, that the table upon which I am writing will suddenly and spontaneously rise into the air. The event requires no more than that the molecules of which the table is composed, ordinarily in random motion in all directions, should happen by chance to move in the same direction. Every physicist concedes this possibility; but try telling one that you have seen it happen. Recently I asked a friend, a Nobel laureate in physics, what he would say if I told him that. He laughed and said that he would regard it as more probable that I was mistaken than that the event had actually occurred.

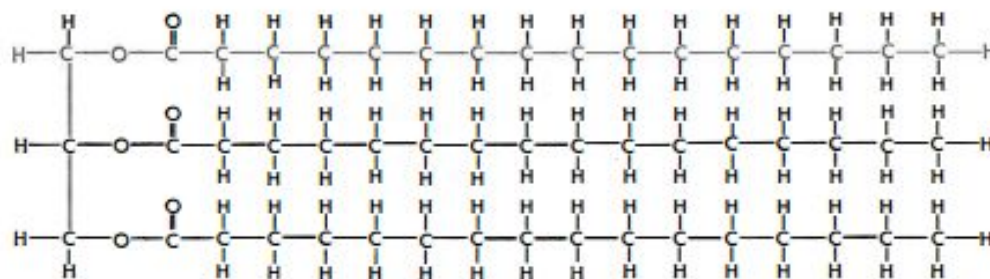
We see therefore that it does not mean much to say that a very improbable event has never been observed. There is a conspiracy to suppress such observations, not among scientists alone, but among all judicious persons, who have learned to be skeptical even of what they see, let alone of what they are told. If one group is more skeptical than others, it is perhaps lawyers, who have the harshest experience of the unreliability of human evidence. Least skeptical of all are the scientists, who, cautious as they are, know very well what strange things are possible.

A final aspect of our problem is very important. When we consider the spontaneous origin of a living organism, this is not an event that need happen again and again. It is perhaps enough for it to happen once. The probability with

which we are concerned is of a special kind; it is the probability that an event occur at least once. To this type of probability a fundamentally important thing happens as one increases the number of trials. However improbable the event in a single trial, it becomes increasingly probable as the trials are multiplied. Eventually the event becomes virtually inevitable. For instance, the chance that a coin will not fall head up in a single toss is 1/2. The chance that no head will appear in a series of tosses is $1/2 \times 1/2 \times 1/2 \dots$ as many times over as the number of tosses. In 10 tosses the chance that no head will appear is therefore $1/2$ multiplied by itself 10 times, or $1/1,000$. Consequently the chance that a head will appear at least once in 10 tosses is $999/1,000$. Ten trials have converted what started as a modest probability to a near certainty.

The same effect can be achieved with any probability, however small, by multiplying sufficiently the number of trials. Consider a reasonably improbable event, the chance of which is $1/1,000$. The chance that this will not occur in one trial is $999/1,000$. The chance that it won't occur in 1,000 trials is $999/1,000$ multiplied together 1,000 times. This fraction comes out to be $37/100$. The chance that it will happen at least once in 1,000 trials is therefore one minus this number— $63/100$ —a little better than three chances out of five. One thousand trials have transformed this from a highly improbable to a highly probable event. In 10,000 trials the chance that this event will occur at least once comes out to be $19,999/20,000$. It is now almost inevitable.

It makes no important change in the argument if we assess the probability that an event occur at least two, three, four or some other small number of



FATS are a second kind of carbon compound found in living matter. This formula represents the whole molecule of palmitic, one of

the commonest fats. The molecule consists of glycerol (12 atoms at the far left) and fatty acids (hydrocarbon chains at the right).

times rather than at least once. It simply means that more trials are needed to achieve any degree of certainty we wish. Otherwise everything is the same.

In such a problem as the spontaneous origin of life we have no way of assessing probabilities beforehand, or even of deciding what we mean by a trial. The origin of a living organism is undoubtedly a stepwise phenomenon, each step with its own probability and its own conditions of trial. Of one thing we can be sure, however: whatever constitutes a trial, more such trials occur the longer the interval of time.

The important point is that since the origin of life belongs in the category of at-least-once phenomena, time is on its side. However improbable we regard this event, or any of the steps which it involves, given enough time it will almost certainly happen at least once. And for life as we know it, with its capacity for growth and reproduction, once may be enough.

Time is in fact the hero of the plot. The time with which we have to deal is of the order of two billion years. What we regard as impossible on the basis of human experience is meaningless here. Given so much time, the "impossible" becomes possible, the possible probable, and the probable virtually certain. One has only to wait: time itself performs the miracles.

Organic Molecules

This brings the argument back to its first stage: the origin of organic compounds. Until a century and a quarter ago the only known source of these substances was the stuff of living organisms. Students of chemistry are usually told that when, in 1828, Friedrich Wöhler synthesized the first organic compound, urea, he proved that organic compounds do not require living organisms to make

them. Of course it showed nothing of the kind. Organic chemists are alive; Wöhler merely showed that they can make organic compounds externally as well as internally. It is still true that with almost negligible exceptions all the organic matter we know is the product of living organisms.

The almost negligible exceptions, however, are very important for our argument. It is now recognized that a constant, slow production of organic molecules occurs without the agency of living things. Certain geological phenomena yield simple organic compounds. So, for example, volcanic eruptions bring metal carbides to the surface of the earth, where they react with water vapor to yield simple compounds of carbon and hydrogen. The familiar type of such a reaction is the process used in old-style bicycle lamps in which acetylene is made by mixing iron carbide with water.

Recently Harold Urey, Nobel laureate in chemistry, has become interested in the degree to which electrical discharges in the upper atmosphere may promote the formation of organic compounds. One of his students, S. L. Miller, performed the simple experiment of circulating a mixture of water vapor, methane (CH₄), ammonia (NH₃) and hydrogen—all gases believed to have been present in the early atmosphere of the earth—continuously for a week over an electric spark. The circulation was maintained by boiling the water in one limb of the apparatus and condensing it in the other. At the end of the week the water was analyzed by the delicate method of paper chromatography. It was found to have acquired a mixture of amino acids! Glycine and alanine, the simplest amino acids and the most prevalent in proteins, were definitely identified in the solution, and there were indications it contained aspartic acid and two others. The yield was surprisingly

high. This amazing result changes at a stroke our ideas of the probability of the spontaneous formation of amino acids.

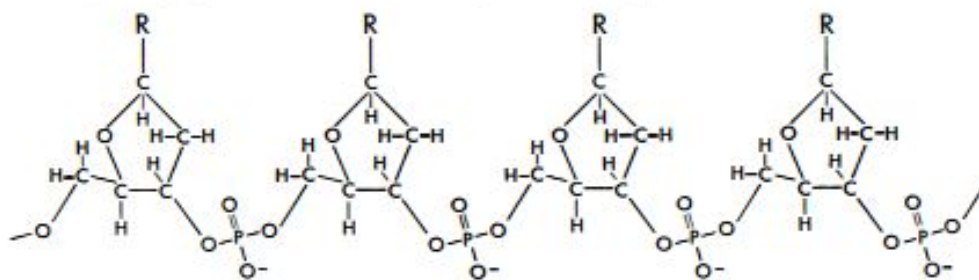
A final consideration, however, seems to me more important than all the special processes to which one might appeal for organic syntheses in inanimate nature.

It has already been said that to have organic molecules one ordinarily needs organisms. The synthesis of organic substances, like almost everything else that happens in organisms, is governed by the special class of proteins called enzymes—the organic catalysts which greatly accelerate chemical reactions in the body. Since an enzyme is not used up but is returned at the end of the process, a small amount of enzyme can promote an enormous transformation of material.

Enzymes play such a dominant role in the chemistry of life that it is exceedingly difficult to imagine the synthesis of living material without their help. This poses a dilemma, for enzymes themselves are proteins, and hence among the most complex organic components of the cell. One is asking, in effect, for an apparatus which is the unique property of cells in order to form the first cell.

This is not, however, an insuperable difficulty. An enzyme, after all, is only a catalyst; it can do no more than change the rate of a chemical reaction. It cannot make anything happen that would not have happened, though more slowly, in its absence. Every process that is catalyzed by an enzyme, and every product of such a process, would occur without the enzyme. The only difference is one of rate.

Once again the essence of the argument is time. What takes only a few moments in the presence of an enzyme or other catalyst may take days, months or years in its absence; but given time, the end result is the same.



NUCLEIC ACIDS are a third kind of carbon compound. This is carbon sugars alternating with phosphoric acid. The letter R is any

part of deoxyribonucleic acid, the backbone of which is five-

one of four nitrogenous bases, two purines and two pyrimidines.

Indeed, this great difficulty in conceiving of the spontaneous generation of organic compounds has its positive side. In a sense, organisms demonstrate to us what organic reactions and products are possible. We can be certain that, given time, all these things must occur. Every substance that has ever been found in an organism displays thereby the finite probability of its occurrence. Hence, given time, it should arise spontaneously. One has only to wait.

It will be objected at once that this is just what one cannot do. Everyone knows that these substances are highly perishable. Granted that, within long spaces of time, now a sugar molecule, now a fat, now even a protein might form spontaneously, each of these molecules should have only a transitory existence. How are they ever to accumulate; and, unless they do so, how form an organism?

We must turn the question around. What, in our experience, is known to destroy organic compounds? Primarily two agencies: decay and the attack of oxygen. But decay is the work of living organisms, and we are talking of a time before life existed. As for oxygen, this introduces a further and fundamental section of our argument.

It is generally conceded at present that the early atmosphere of our planet contained virtually no free oxygen. Almost all the earth's oxygen was bound in the form of water and metal oxides. If this were not so, it would be very difficult to imagine how organic matter could accumulate over the long stretches of time that alone might make possible the spontaneous origin of life. This is a crucial point, therefore, and the statement that the early atmosphere of the planet was virtually oxygen-free comes forward so opportunely as to raise a suspicion of special pleading. I have for this reason taken care to consult a number of

geologists and astronomers on this point, and am relieved to find that it is well defended. I gather that there is a widespread though not universal consensus that this condition did exist. Apparently something similar was true also for another common component of our atmosphere—carbon dioxide. It is believed that most of the carbon on the earth during its early geological history existed as the element or in metal carbides and hydrocarbons; very little was combined with oxygen.

This situation is not without its irony. We tend usually to think that the environment plays the tune to which the organism must dance. The environment is given; the organism's problem is to adapt to it or die. It has become apparent lately, however, that some of the most important features of the physical environment are themselves the work of living organisms. Two such features have just been named. The atmosphere of our planet seems to have contained no oxygen until organisms placed it there by the process of plant photosynthesis. It is estimated that at present all the oxygen of our atmosphere is renewed by photosynthesis once in every 2,000 years, and that all the carbon dioxide passes through the process of photosynthesis once in every 300 years. In the scale of geological time, these intervals are very small indeed. We are left with the realization that all the oxygen and carbon dioxide of our planet are the products of living organisms, and have passed through living organisms over and over again.

Forces of Dissolution

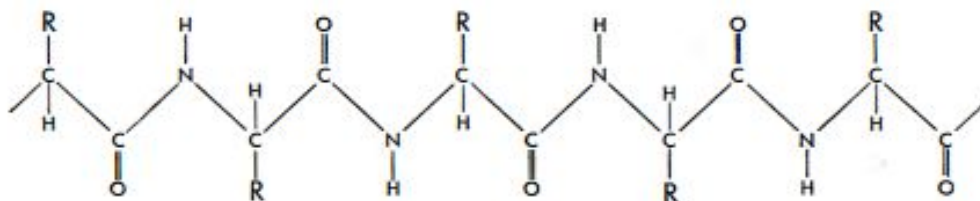
In the early history of our planet, when there were no organisms or any free oxygen, organic compounds should have been stable over very long periods. This is the crucial difference between

the period before life existed and our own. If one were to specify a single reason why the spontaneous generation of living organisms was possible once and is so no longer, this is the reason.

We must still reckon, however, with another destructive force which is disposed of less easily. This can be called spontaneous dissolution—the counterpart of spontaneous generation. We have noted that any process catalyzed by an enzyme can occur in time without the enzyme. The trouble is that the processes which synthesize an organic substance are reversible: any chemical reaction which an enzyme may catalyze will go backward as well as forward. We have spoken as though one has only to wait to achieve syntheses of all kinds; it is truer to say that what one achieves by waiting is *equilibria* of all kinds—equilibria in which the synthesis and dissolution of substances come into balance.

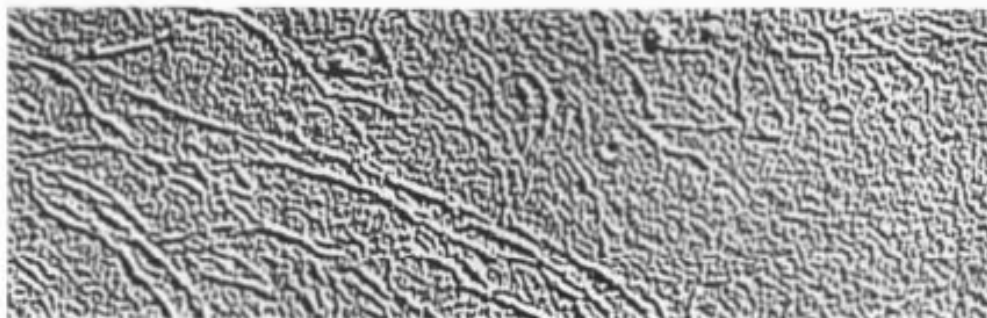
In the vast majority of the processes in which we are interested the point of equilibrium lies far over toward the side of dissolution. That is to say, spontaneous dissolution is much more probable, and hence proceeds much more rapidly, than spontaneous synthesis. For example, the spontaneous union, step by step, of amino acid units to form a protein has a certain small probability, and hence might occur over a long stretch of time. But the dissolution of the protein or of an intermediate product into its component amino acids is much more probable, and hence will go ever so much more rapidly. The situation we must face is that of patient Penelope waiting for Odysseus, yet much worse: each night she undid the weaving of the preceding day, but here a night could readily undo the work of a year or a century.

How do present-day organisms manage to synthesize organic compounds against the forces of dissolution? They do so by a continuous expenditure of



PROTEINS are a fourth kind of carbon compound found in living matter. This formula represents part of a polypeptide chain, the

backbone of a protein molecule. The chain is made up of amino acids. Here the letter R represents the side chains of these acids.



FILAMENTS OF COLLAGEN, a protein which is usually found in long fibrils, were dispersed by placing them in dilute acetic acid. This electron micrograph, which enlarges the filaments 75,000 times, was made by Jerome Gross of the Harvard Medical School.

energy. Indeed, living organisms commonly do better than oppose the forces of dissolution; they grow in spite of them. They do so, however, only at enormous expense to their surroundings. They need a constant supply of material and energy merely to maintain themselves, and much more of both to grow and reproduce. A living organism is an intricate machine for performing exactly this function. When, for want of fuel or through some internal failure in its mechanism, an organism stops actively synthesizing itself in opposition to the processes which continuously decompose it, it dies and rapidly disintegrates.

What we ask here is to synthesize organic molecules without such a machine. I believe this to be the most stubborn problem that confronts us—the weakest link at present in our argument. I do not think it by any means disastrous, but it calls for phenomena and forces some of which are as yet only partly understood and some probably still to be discovered.

Forces of Integration

At present we can make only a beginning with this problem. We know that it is possible on occasion to protect molecules from dissolution by precipitation or by attachment to other molecules. A wide variety of such precipitation and "trapping" reactions is used in modern chemistry and biochemistry to promote syntheses. Some molecules appear to acquire a degree of resistance to disintegration simply through their size. So, for example, the larger molecules composed of amino acids—polypeptides and proteins—seem to display much less tendency to disintegrate into their units than do smaller compounds of two or three amino acids.

Again, many organic molecules dis-

play still another type of integrating force—a spontaneous impulse toward structure formation. Certain types of fatty molecules—lecithins and cephalins—spin themselves out in water to form highly oriented and well-shaped structures—the so-called myelin figures. Proteins sometimes orient even in solution, and also may aggregate in the solid state in highly organized formations. Such spontaneous architectonic tendencies are still largely unexplored, particularly as they may occur in complex mixtures of substances, and they involve forces the strength of which has not yet been estimated.

What we are saying is that possibilities exist for opposing intramolecular dissolution by intermolecular aggregations of various kinds. The equilibrium between union and disunion of the amino acids that make up a protein is all to the advantage of disunion, but the aggregation of the protein with itself or other molecules might swing the equilibrium in the opposite direction: perhaps by removing the protein from access to the water which would be required to disintegrate it or by providing some particularly stable type of molecular association.

In such a scheme the protein appears only as a transient intermediate, an unstable way-station, which can either fall back to a mixture of its constituent amino acids or enter into the formation of a complex structural aggregate: amino acids \rightleftharpoons protein \rightarrow aggregate.

Such molecular aggregates, of various degrees of material and architectural complexity, are indispensable intermediates between molecules and organisms. We have no need to try to imagine the spontaneous formation of an organism by one grand collision of its component molecules. The whole process must

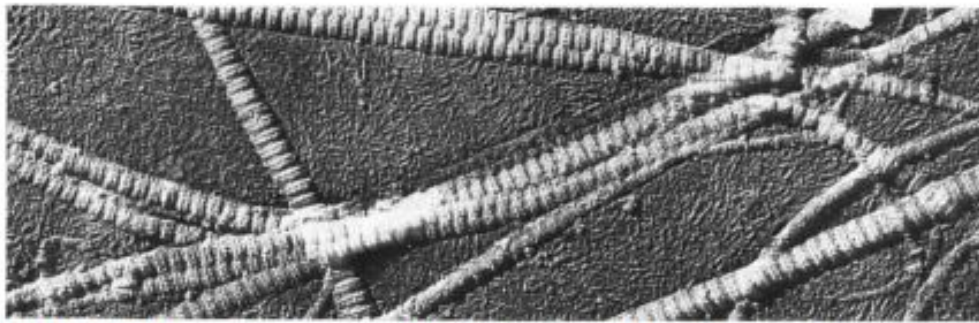
be gradual. The molecules form aggregates, small and large. The aggregates add further molecules, thus growing in size and complexity. Aggregates of various kinds interact with one another to form still larger and more complex structures. In this way we imagine the ascent, not by jumps or master strokes, but gradually, piecemeal, to the first living organisms.

First Organisms

Where may this have happened? It is easiest to suppose that life first arose in the sea. Here were the necessary salts and the water. The latter is not only the principal component of organisms, but prior to their formation provided a medium which could dissolve molecules of the widest variety and ceaselessly mix and circulate them. It is this constant mixture and collision of organic molecules of every sort that constituted in large part the "trials" of our earlier discussion of probabilities.

The sea in fact gradually turned into a dilute broth, sterile and oxygen-free. In this broth molecules came together in increasing number and variety, sometimes merely to collide and separate, sometimes to react with one another to produce new combinations, sometimes to aggregate into multimolecular formations of increasing size and complexity.

What brought order into such complexes? For order is as essential here as composition. To form an organism, molecules must enter into intricate designs and connections; they must eventually form a self-repairing, self-constructing dynamic machine. For a time this problem of molecular arrangement seemed to present an almost insuperable obstacle in the way of imagining a spontaneous origin of life, or indeed the laboratory



FIBRILS OF COLLAGEN formed spontaneously out of filaments such as those shown on the opposite page when 1 per cent of sodium chloride was added to the dilute acetic acid. These long fibrils are identical in appearance with those of collagen before dispersion.

synthesis of a living organism. It is still a large and mysterious problem, but it no longer seems insuperable. The change in view has come about because we now realize that it is not altogether necessary to bring order into this situation; a great deal of order is implicit in the molecules themselves.

The epitome of molecular order is a crystal. In a perfect crystal the molecules display complete regularity of position and orientation in all planes of space. At the other extreme are fluids—liquids or gases—in which the molecules are in ceaseless motion and in wholly random orientations and positions.

Lately it has become clear that very little of a living cell is truly fluid. Most of it consists of molecules which have taken up various degrees of orientation with regard to one another. That is, most of the cell represents various degrees of approach to crystallinity—often, however, with very important differences from the crystals most familiar to us. Much of the cell's crystallinity involves molecules which are still in solution—so-called liquid crystals—and much of the dynamic, plastic quality of cellular structure, the capacity for constant change of shape and interchange of material, derives from this condition. Our familiar crystals, furthermore, involve only one or a very few types of molecule, while in the cell a great variety of different molecules come together in some degree of regular spacing and orientation—i.e., some degree of crystallinity. We are dealing in the cell with highly mixed crystals and near-crystals, solid and liquid. The laboratory study of this type of formation has scarcely begun. Its further exploration is of the highest importance for our problem.

In a fluid such as water the molecules are in very rapid motion. Any molecules

dissolved in such a medium are under a constant barrage of collisions with water molecules. This keeps small and moderately sized molecules in a constant turmoil; they are knocked about at random, colliding again and again, never holding any position or orientation for more than an instant. The larger a molecule is relative to water, the less it is disturbed by such collisions. Many protein and nucleic acid molecules are so large that even in solution their motions are very sluggish, and since they carry large numbers of electric charges distributed about their surfaces, they tend even in solution to align with respect to one another. It is so that they tend to form liquid crystals.

We have spoken above of architectonic tendencies even among some of the relatively small molecules: the lecithins and cephalins. Such molecules are insoluble in water yet possess special groups which have a high affinity for water. As a result they tend to form surface layers, in which their water-seeking groups project into the water phase, while their water-repelling portions project into the air, or into an oil phase, or unite to form an oil phase. The result is that quite spontaneously such molecules, when exposed to water, take up highly oriented positions to form surface membranes, myelin figures and other quasi-crystalline structures.

Recently several particularly striking examples have been reported of the spontaneous production of familiar types of biological structure by protein molecules. Cartilage and muscle offer some of the most intricate and regular patterns of structure to be found in organisms. A fiber from either type of tissue presents under the electron microscope a beautiful pattern of cross striations of various widths and densities, very regularly spaced. The proteins that form these

structures can be coaxed into free solution and stirred into completely random orientation. Yet on precipitating, under proper conditions, the molecules realign with regard to one another to regenerate with extraordinary fidelity the original patterns of the tissues [see illustration above].

We have therefore a genuine basis for the view that the molecules of our oceanic broth will not only come together spontaneously to form aggregates but in doing so will spontaneously achieve various types and degrees of order. This greatly simplifies our problem. What it means is that, given the right molecules, one does not have to do everything for them; they do a great deal for themselves.

Oparin has made the ingenious suggestion that natural selection, which Darwin proposed to be the driving force of organic evolution, begins to operate at this level. He suggests that as the molecules come together to form colloidal aggregates, the latter begin to compete with one another for material. Some aggregates, by virtue of especially favorable composition or internal arrangement, acquire new molecules more rapidly than others. They eventually emerge as the dominant types. Oparin suggests further that considerations of optimal size enter at this level. A growing colloidal particle may reach a point at which it becomes unstable and breaks down into smaller particles, each of which grows and redivides. All these phenomena lie within the bounds of known processes in nonliving systems.

The Sources of Energy

We suppose that all these forces and factors, and others perhaps yet to be revealed, together give us eventually the

first living organism. That achieved, how does the organism continue to live?

We have already noted that a living organism is a dynamic structure. It is the site of a continuous influx and outflow of matter and energy. This is the very sign of life, its cessation the best evidence of death. What is the primal organism to use as food, and how derive the energy it needs to maintain itself and grow?

For the primal organism, generated under the conditions we have described, only one answer is possible. Having arisen in an oceanic broth of organic molecules, its only recourse is to live upon them. There is only one way of doing that in the absence of oxygen. It is called fermentation: the process by

which organisms derive energy by breaking organic molecules and rearranging their parts. The most familiar example of such a process is the fermentation of sugar by yeast, which yields alcohol as one of the products. Animal cells also ferment sugar, not to alcohol but to lactic acid. These are two examples from a host of known fermentations.

The yeast fermentation has the following over-all equation: $C_6H_{12}O_6 \rightarrow 2 CO_2 + 2 C_2H_5OH + \text{energy}$. The result of fragmenting 180 grams of sugar into 88 grams of carbon dioxide and 92 grams of alcohol is to make available about 20,000 calories of energy for the use of the cell. The energy is all that the cell

derives by this transaction; the carbon dioxide and alcohol are waste products which must be got rid of somehow if the cell is to survive.

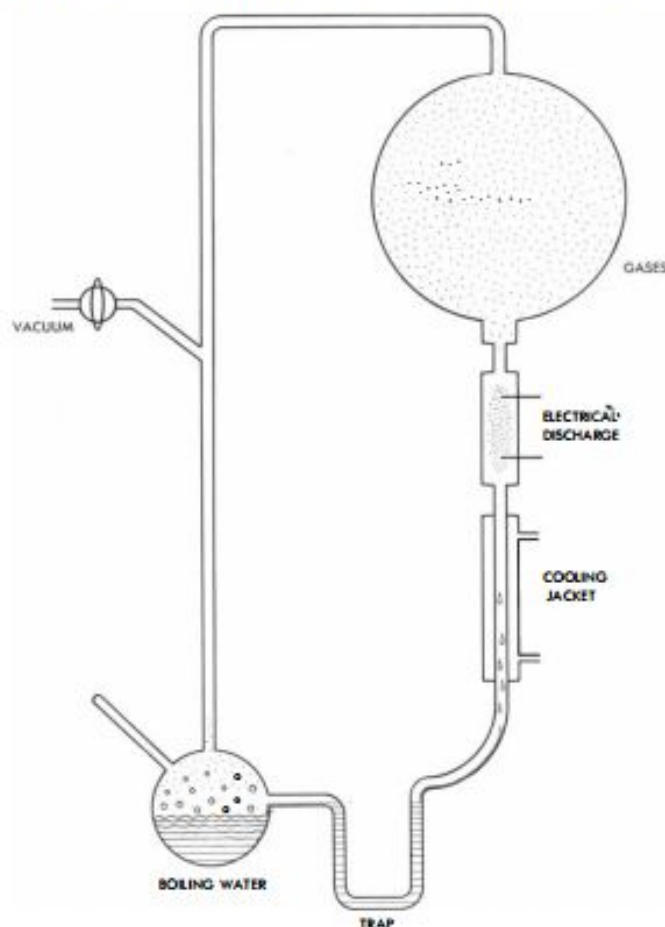
The cell, having arisen in a broth of organic compounds accumulated over the ages, must consume these molecules by fermentation in order to acquire the energy it needs to live, grow and reproduce. In doing so, it and its descendants are living on borrowed time. They are consuming their heritage, just as we in our time have nearly consumed our heritage of coal and oil. Eventually such a process must come to an end, and with that life also should have ended. It would have been necessary to start the entire development again.

Fortunately, however, the waste product carbon dioxide saved this situation. This gas entered the ocean and the atmosphere in ever-increasing quantity. Some time before the cell exhausted the supply of organic molecules, it succeeded in inventing the process of photosynthesis. This enabled it, with the energy of sunlight, to make its own organic molecules: first sugar from carbon dioxide and water, then, with ammonia and nitrates as sources of nitrogen, the entire array of organic compounds which it requires. The sugar synthesis equation is: $6 CO_2 + 6 H_2O + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6 O_2$. Here 264 grams of carbon dioxide plus 108 grams of water plus about 700,000 calories of sunlight yield 180 grams of sugar and 192 grams of oxygen.

This is an enormous step forward. Living organisms no longer needed to depend upon the accumulation of organic matter from past ages; they could make their own. With the energy of sunlight they could accomplish the fundamental organic syntheses that provide their substance, and by fermentation they could produce what energy they needed.

Fermentation, however, is an extraordinarily inefficient source of energy. It leaves most of the energy potential of organic compounds unexploited; consequently huge amounts of organic material must be fermented to provide a modicum of energy. It produces also various poisonous waste products—alcohol, lactic acid, acetic acid, formic acid and so on. In the sea such products are readily washed away, but if organisms were ever to penetrate to the air and land, these products must prove a serious embarrassment.

One of the by-products of photosynthesis, however, is oxygen. Once this was available, organisms could invent a new way to acquire energy, many times as efficient as fermentation. This is the



EXPERIMENT of S. L. Miller made amino acids by circulating methane (CH_4), ammonia (NH_3), water vapor (H_2O) and hydrogen (H_2) past an electrical discharge. The amino acids collected at the bottom of apparatus and were detected by paper chromatography.

process of cold combustion called respiration: $C_6H_{12}O_6 + 6 O_2 \rightarrow 6 CO_2 + 6 H_2O + \text{energy}$. The burning of 180 grams of sugar in cellular respiration yields about 700,000 calories, as compared with the approximately 20,000 calories produced by fermentation of the same quantity of sugar. This process of combustion extracts all the energy that can possibly be derived from the molecules which it consumes. With this process at its disposal, the cell can meet its energy requirements with a minimum expenditure of substance. It is a further advantage that the products of respiration—water and carbon dioxide—are innocuous and easily disposed of in any environment.

Life's Capital

It is difficult to overestimate the degree to which the invention of cellular respiration released the forces of living organisms. No organism that relies wholly upon fermentation has ever amounted to much. Even after the advent of photosynthesis, organisms could have led only a marginal existence. They could indeed produce their own organic materials, but only in quantities sufficient to survive. Fermentation is so profligate a way of life that photosynthesis could do little more than keep up with it. Respiration used the material of organisms with such enormously greater efficiency as for the first time to leave something over. Coupled with fermentation, photosynthesis made organisms self-sustaining; coupled with respiration, it provided a surplus. To use an economic analogy, photosynthesis brought organisms to the subsistence level; respiration provided them with capital. It is mainly this capital that they invested in the great enterprise of organic evolution.

The entry of oxygen into the atmosphere also liberated organisms in another sense. The sun's radiation contains ultraviolet components which no living cell can tolerate. We are sometimes told that if this radiation were to reach the earth's surface, life must cease. That is not quite true. Water absorbs ultraviolet radiation very effectively, and one must conclude that as long as these rays penetrated in quantity to the surface of the earth, life had to remain under water. With the appearance of oxygen, however, a layer of ozone formed high in the atmosphere and absorbed this radiation. Now organisms could for the first time emerge from the water and begin to populate the earth and air. Oxygen provided not only the means of obtaining adequate energy for evolution but

the protective blanket of ozone which alone made possible terrestrial life.

This is really the end of our story. Yet not quite the end. Our entire concern in this argument has been to bring the origin of life within the compass of natural phenomena. It is of the essence of such phenomena to be repetitive, and hence, given time, to be inevitable.

This is by far our most significant conclusion—that life, as an orderly natural event on such a planet as ours, was inevitable. The same can be said of the whole of organic evolution. All of it lies within the order of nature, and apart from details all of it was inevitable.

Astronomers have reason to believe that a planet such as ours—of about the earth's size and temperature, and about as well-lighted—is a rare event in the universe. Indeed, filled as our story is with improbable phenomena, one of the least probable is to have had such a body as the earth to begin with. Yet though this probability is small, the universe is so large that it is conservatively estimated at least 100,000 planets like the earth exist in our galaxy alone. Some 100 million galaxies lie within the range of our most powerful telescopes, so that throughout observable space we can count apparently on the existence of at least 10 million million planets like our own.

What it means to bring the origin of life within the realm of natural phenomena is to imply that in all these places life probably exists—life as we know it. Indeed, I am convinced that there can be no way of composing and constructing living organisms which is fundamentally different from the one we know—though this is another argument, and must await another occasion. Wherever life is possible, given time, it should arise. It should then ramify into a wide array of forms, differing in detail from those we now observe (as did earlier organisms on the earth) yet including many which should look familiar to us—perhaps even men.

We are not alone in the universe, and do not bear alone the whole burden of life and what comes of it. Life is a cosmic event—so far as we know the most complex state of organization that matter has achieved in our cosmos. It has come many times, in many places—places closed off from us by impenetrable distances, probably never to be crossed even with a signal. As men we can attempt to understand it, and even somewhat to control and guide its local manifestations. On this planet that is our home, we have every reason to wish it well. Yet should we fail, all is not lost. Our kind will try again elsewhere.

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53

