“Hands-On” History:
An innovative course in history of science to improve undergraduate education

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1 ABSTRACT

This Interactive Qualifying Project researched and tested the effects of hands-on learning in multidisciplinary courses and the implications of a more interactive classroom on the future of education. Based on research in educational psychology, interactive learning activities were designed and tested in a course at Worcester Polytechnic Institute. The research was used to design a course in history and science and sample materials are included.

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3 EXECUTIVE SUMMARY

3.1 THE HISTORY OF SCIENCE: PROBLEM STATEMENT

With an ever-increasing emphasis on STEM (science, technology, engineering, and mathematics) disciplines in our modern society, the humanities and liberal arts are undeservingly given far less attention. To address this detrimental effect, a recent report "The Heart of the Matter" from the American Academy's Commission on the Humanities and Social Sciences made an avid case for the importance of the humanities and social sciences to the future of our nation. While the scientific community has been working diligently on strengthening STEM education with direction from the National Academies following the release of their report "Rising Above the Gathering Storm," members of the American Academy have put forward a complementary campaign to advance the mastery of humanities and social sciences. The pressing need for these national efforts arose from the society-driven mistaken dichotomy that the liberal arts and STEM disciplines are fundamentally different. However, both the American Academy and the National Academies argue that STEM and liberal arts are not mutually exclusive and that, in fact, they cannot be separated. To cultivate students who are "educated in the broadest possible sense," there must be a stronger shift toward one of the most important trends in higher education – the emergence of interdisciplinarity (Commission on the Humanities and Social Sciences, 2013). Interdisciplinary teaching can be used as a tool to reverse an increasingly fragmented curriculum by incorporating seemingly detached yet deeply intertwined academic disciplines, such as science and history, into one rigorous interdisciplinary course to provide students with the most complete and well-rounded education possible. To help students see science in its historical context, the "Engage to Excel" report from the President's Council of Advisors on Science and Technology advocates for a shift toward a more hands-on and discovery-based instructional approach. This interactive pedagogical initiative is expected to engage more students and thereby improve the current state of interdisciplinary education.

Below, we review the evidence of the need for such a course and address how educators can use history as a tool in teaching science and how science can be used to convey historical concepts.

3.2 THE HISTORY OF SCIENCE: COMMON MISCONCEPTIONS

It is unfortunately common for students to hold a wide variety of misconceptions about the nature of science, its history and how it has evolved over the years (Wandersee, 1986). These misconceptions usually arise because students are not given opportunities to learn about science and its contextual intricacy, and as a result develop significant gaps in their knowledge. The majority of science textbooks are written in ways that detail the work of pioneering scientists largely in terms of their contribution to what we now regard as established knowledge (Irwin, 1997). With the benefit of hindsight, textbook authors are tempted to evaluate past science against present knowledge and to reduce historic content to only successful, methodical examples of scientific progress. This heavily idealized representation of science, known as the "Whig view," ultimately provides students with biased accounts of historic events which distort their understanding of the way in which scientific knowledge grows (Brush, 1997). For example, according to the Whig view of the history of science, Fleming's discovery of penicillin is likely to be portrayed as one glorious achievement by a brilliant scientist marking a turning point in the course of modern medicine. However, a more realistic account would demonstrate that Fleming's discovery was nothing short of a fortuitous event, contingent on problems faced by medical research and rampant infection rates, the particular weather conditions which happened to allow the mold to grow, the power of observation and genuine curiosity, and that even then, the medicinal application of mold was delayed for years before other scientists found methods for purifying and producing it in commercial quantities (Monk & Osborne, 1997). Paradoxically, many other role models that have been carefully constructed by science education – for example, of Newton, Darwin, Einstein, and Curie – have all become superhuman and consequently seem hopelessly unattainable for many students. Overwhelmed by these deceptive representations, students begin to regard science as a mere celebration of breakthrough discoveries and genius scientists conjuring up answers from thin air (Wittaker, 1979). Instead of recognizing the work of scientists as inspirational, students adopt a more patronizing attitude.

Modern education, in its majority, fails to emphasize that renowned discoverers are not the only exemplars of good scientists. In fact, their favorably biased portraits twist the idea of what it really means to be a scientist. This historical division of scientist into "winners" and "losers" has greatly obscured the authenticity of contributions made toward scientific progress. By choosing to not convey examples of what would be considered unsuccessful science, textbook authors are not only misrepresenting history but are also distorting the reality of the way science actually works. The lack of exposure to authentic research and overemphasis of the scientific method cause students to regard science as a teleological process without any immediate appreciation for simply what it is, with all its novelties as well as major obstacles and even failures (Miller, 1987). Studies show that many students share a misguided view of the origins of scientific ideas and tend to principally associate the growth of scientific knowledge with incidental discoveries while dismissing the importance of human imagination as a source of powerful ideas. This flawed epistemological view pushes students to believe that science is a "gospel of unassailable truths" and that scientific progress consists of discovering them (Irwin, 1997).

While changing popular beliefs as a whole would be an impossibly big undertaking, integrating a history of science course that would re-establish the intrinsic value of science and stress science as a human endeavor may be a more feasible remedy for educators. Studies suggest that students should be exposed more to the "how of scientific enquiry," rather than merely learning what is known about and by science today (Kyle, 1997). Students' understanding of the nature of science can be facilitated using historic cases that would highlight accomplishments as much as struggles and defeats faced by our scientific predecessors in the context of the knowledge available to them at the time. For example, the development of the atomic theory – from some of Dalton's incorrect assumptions about the atom to our modern understanding of its quantized nature – is a suitable means of showing how scientific theories change and evolve over time. Appropriate historic context would include descriptions of previous scientists' experiments, discussions of their ideas, intellectual and cultural problems, and debates. A stronger emphasis on conveying a proper historic image of the real science is needed to help dissipate the prevailing view of science as absolute and objective, and instead to illustrate the power of the human mind in making strides toward scientific progress (Liu & Tsai, 2008). Moreover, integrating history in science teaching can personalize and humanize science to make the learning more real to students. History may thus help to recruit more participants in science, while science may showcase the usually unspoken importance of having proper historic knowledge.

4 INTRODUCTION

4.1 CURRENT COURSES IN HISTORY OF SCIENCE

4.1.1 Design

Worcester Polytechnic Institute (WPI) has already implemented an action plan to dissipate some of the common misconceptions by offering a number of specific courses focusing on the history of science including "History of the Life Sciences," "History of the Physical Sciences," "History of Evolutionary Thought," and many others (Office of the Provost, 2013). These current courses put scientific events into proper context by providing relevant historical background. Professors who teach these history of science courses run their classes slightly differently from each other, and it is important to recognize these differences in their teaching methods to determine effective strategies, and where new strategies could be introduced. (See Appendix A for a full list of courses currently offered at WPI).

For examples, in courses taught by Professor David Spanagel, Assistant Professor of the WPI Humanities and Arts Department, lectures are almost entirely discussion-based, and each day one student is assigned to take notes for the whole class to allow everyone to fully engage and contribute to the discussion. Some lectures include videos that professors believe demonstrate a topic or a theme particularly well. Students are expected to read nearly every day in all courses, and readings typically include excerpts from original publications, deliberately contradicting articles, and chapters from books used throughout the course. Professors regularly assign essays to help students develop their abilities to perform research and defend their ideas. Some classes rely heavily on these essays for grading, but several also incorporate exams or weekly quizzes. Courses taught by Professor Constance Clark, Associate Professor of the WPI Humanities and Arts Department, incorporate additional "mini-labs" during lecture periods to simulate experiments and put students in the mindset of true scientists. Each of the aforementioned activities share aspects that are beneficial for students, and others that could be improved upon by designing a new course.

After reviewing evaluations from students enrolled in history of science and technology courses at WPI in the 2012-2013 academic year, a few topics were found to be especially prevalent and helpful (C. Clark & D. Spanagel, personal communication, 2013). In the "History of the Life Sciences" taught by Professor Clark, three learning activities were commonly appraised on the evaluations: presentations, discussions (both class and group), and "mini-labs." Students enjoyed these activities as a break from the typical lecture-based course because they could be actively participating in their own education and learning, rather than passively observing and regurgitating information. The mini-labs consisted of either short activities done in small groups or demonstrations performed by the professor to teach a concept. These were commonly praised by the students and were described as "a great way to apply what we were reading about." Numerous other comments from students articulated the importance of laboratory experience in a history class and how it positively impacted their learning. Specific comments mentioned that "mini-labs" help to "establish the understanding that painstaking laboratorial work was performed to gain evidence so we can relate to historical figures" and that they "really help to give more insight and thought on how theories developed." Not a single student commented that the labs detracted from the course, and on the contrary, many wanted to see more labs. With this feedback in mind, a major goal of the proposed course is to incorporate a significant laboratory portion. The only recurring negative reviews found among the evaluations addressed the classroom space and that it was not always "suitable for labs." Students further suggested to "get a better room for labs" and that it "would be better suited for hands-on aspects." Some students made suggestions on how the mini-labs can be improved if they were "closer to lecture topics," "provided more background," discussed "impact on society," and contained "out of class questions" that would allow student to reflect back on the work done in class. In Professor Spanagel's history of science courses, students did not participate in any lab activities, but primary-source discussion workshops were also popular because they provided students with the opportunity to "learn by hearing views from the perspective of other students," and to "communicate their ideas" to a group of individuals willing to listen to them. Some students even commented on how it was "difficult to become bored or tired" during classes taught by both of the professors' classes because they were "highly interactive." A substantial number of reviews focused on class structure, for example, eight students said that the "class was too long at 2 hours" and another ten students thought that "there was too much reading." With this information in mind, the designed course will incorporate as many elements from these courses as would be appropriate, with a strong emphasis on hands-on laboratory activities.

4.1.2 Current problems

While the current courses have addressed many of the misconceptions about the history of science, there is a strong need for creating a new course, with several design differences some of which were directly pointed in students' evaluations. Many classes at WPI such as "The History of Life Sciences" and "The History of the Exact Sciences" focus on narrow fields of study, while other classes focus on specific time periods such as in the "Science, Technology, and Culture in the Early American Republic" (Office of the Provost, 2013). This course would address science from different time periods and different areas of study in order to demonstrate the crucial idea that science is not isolated in either of these respects. The most significant aspect of the current courses that we would like to expand upon are the small scale laboratory experiences referred to as "mini-labs." These experiences received a lot of praise from the students, however, they are limited by the availability of resources such as adequate laboratory space and materials, as well as sufficient time to cover all the topics. Sometimes there are not quite enough lab materials for all groups to have access to them, and so they do not get the chance to work with them as much as a lab component should entail. Plus, some of these lab experiences are integrated into the lectures, which present them as an interactive classroom activity rather than a full laboratory experience.

It is important to consider the probable enrollment of a course before attempting to implement the course at a university. At WPI, there has been continuous over-enrollment within the science and technology related history courses at the 1000 and 2000 levels. According to Professor Spanagel, “You could clone both Professor Clark and myself and we still would not have enough time to teach all of the courses that WPI students would be willing to take in the history of sciences” (D. Spanagel, personal communication, 2013). Over the past five years, multiple courses showed greater than or equal to 100% enrollment (Registrar’s Office, 2013), with the average course enrollment in ten different history courses relating to either science or technology being 97% (see Table 1). The statistic of 100% enrollment is based on the number of available seats listed for course registration. The available seats in these classes ranged from 25 to 50 students.

Table 1

Enrollment Statistics for WPI Science and Technology Related History Courses From 2008 to 2013

Course	Min	Max	Average
HI 1331: Introduction to the History of Science	93%	104%	99%
HI 1332: Introduction to the History of Technology	96%	112%	104%
HI 2330: Science, Technology, and Culture in the Early American Republic	82%	82%	82%
HI 2331: History of Modern American Science and Technology	96%	100%	99%
HI 2333: History of the Life Sciences	86%	90%	89%
HI 2351: History of the Physical Sciences	100%	100%	100%
HI 2352: History of Ecology	96%	96%	96%
HI 2353: History of American Science and Technology	108%	108%	108%
HI 2354: History of Science	100%	100%	100%
HI 2402: History of Evolutionary Thought	76%	108%	92%
		Overall Average Enrollment	97%

In addition to the problem of classroom capacity, WPI is experiencing rapid growth in student population. In 2007, the WPI admissions office stated that “WPI typically enrolls a freshman class of around 800.” In 2011, the incoming freshman class had 1,023 students pay a deposit with the intent of enrolling at WPI and the freshman class in 2013 started the year with 1,316 students (Office of Undergraduate Admissions, 2013). As evidenced by Table 1, the recurring over-enrollment in some of these courses presents an immediate problem, while high enrollment in others, coupled with a growing freshman class size (see Figure 1), will likely become an increasingly noticeable problem with a potential for over-enrollment in the near future. If the incoming class size continues to grow, WPI will need to develop additional course options in order to accommodate the apparent interest in the history courses related to science and technology.

The trend of increasing first-year class size indicates a need for more available classes for freshmen. Also, the trend of over enrollment in history of science courses suggests that WPI should increase the number of available courses dealing with the history of science. In order to solve both of these problems it would be beneficial for the school to implement the hands-on history of science course. The laboratory sections will have the same capacity as the lecture, meaning it will not be a limiting factor as it often is in classes such as the introductory chemistry series. Based on this information implementation of the hands-on history of science course here at WPI in the near future would help to alleviate some of the course capacity problems that WPI is experiencing as a result of the problems highlighted above.

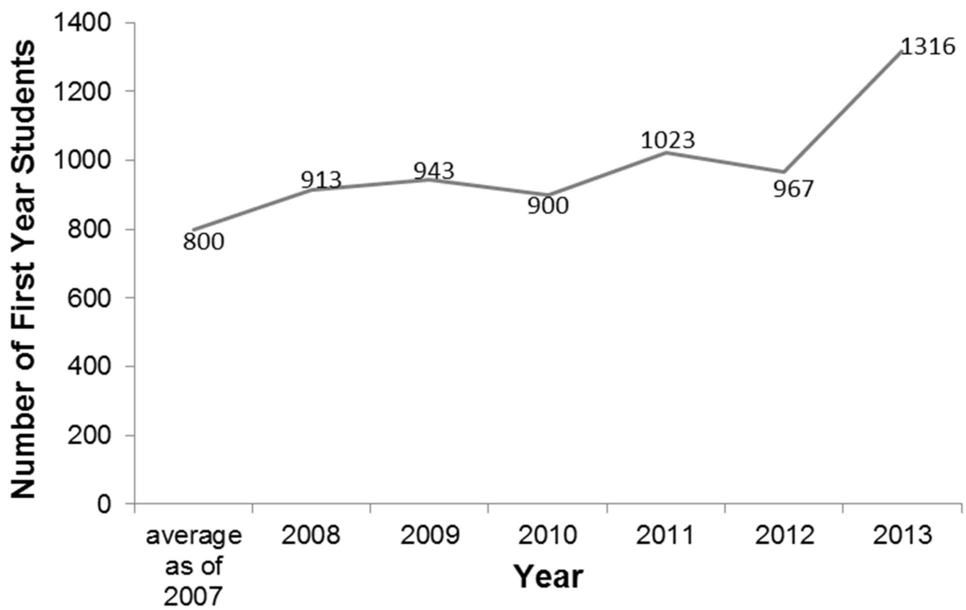

Figure 1. Size of Freshman Class Each Year from 2007 to 2013.

4.2 PROPOSED COURSE IN HISTORY OF SCIENCE

4.2.1 Overview

All of the aforementioned problems can be resolved by adding an experimental course in the history of sciences. The growing freshmen class size suggests that WPI will need more class sections available for the students to take. The fact that science related history courses are often highly enrolled, or over enrolled, means that a new course in this field may be necessary. An intro college-level course in the history of sciences field will address both of these problems. However, there is also a problem of the method of education in the classroom. In order to address this problem the proposed course contains hands-on activities and other non-traditional teaching techniques to improve the overall learning by the students.

The course being proposed is a freshmen level course that combines both history and science. There are already courses available that do this. The difference between the existing courses and the proposed course is the involvement the students will have. Students will be doing hands-on activities such as laboratory experiments that will take place in a laboratory space, with sufficient supplies for all of the students to participate. The new course will also utilize a conference section to address the cultural aspects of the history of science. In these conference sections students will discuss and present various cultural aspects that pertain to material being covered in the lecture. This helps to give a "big picture" feeling to the course. It is important for the students in the course to understand how scientific progress really happens. This means they may have failed experiments, they may have unexpected results, but it also means that the students need to understand the pressure of society that the scientists had to contend with. The course will have some traditional lecturing as well which will help to keep the class on track for the learning objectives of the course. This combination of educational and learning styles will create an atmosphere of learning suited to a wider variety of students by requiring active participation and through the implementation of hands-on learning.

This course is meant to create a mindset which will help students in future science classes. This mindset will be addressed within the lectures as the class learns about discoveries that changed scientific thinking. The course will encourage students to interpret what the results of an experiment mean. This includes encouraging students to work on their conclusions assuming the data obtained is accurate and then explain the implication of their results. This is different from normal lab classes where if the data does not match the expected results the question students are expected to answer is “what went wrong?” It will also help to develop appreciation for the difficulties and messiness of science. This will be fostered by the laboratory experiments that will force the students to use their creative and critical thinking to complete. Conference sections will also be important for emphasizing the difficulties faced by scientists, especially those who are making the biggest discoveries.

The “Hands on History” course will be different from existing courses because it will be hands on. This course will utilize laboratories experiments to enhance the students learning experience. The units for this course will also cover a broader range of topics than the existing courses. This is so the proposed course can address scientific progress as a big picture. The course will address how culture impacts scientific discovery, and how the mindset of a society may impede scientific progress.

4.2.2 Design

The proposed course, “Hands on History,” will follow the history of the major events in various fields of science. Events in one field of study influence the progress in other fields of study, therefore integrating them into one course will teach students that scientific fields are not independent of each other. Also, scientists do not work in isolation; otherwise they would be constantly reinventing the wheel so to speak, so showing students how scientists influenced each other, for better or for worse, will demonstrate that every discovery did not occur as an isolated event. “Hands on History” is expected to incorporate key aspects from currently offered courses, along with topics which are not covered in the aforementioned and other similar courses, to create a single interdisciplinary course that will highlight important discoveries and revelations in the major disciplines of science including chemistry, biology, and physics which will be split up into distinct units. The projected course will run for one semester, or two terms, which will allocate enough time for the students to become immersed in the historical context. The information covered will demonstrate the process leading up to these discoveries, as well as their historical importance. In order to convey the process by which scientists were able to make such discoveries, this course will incorporate a lab component, exemplifying the processes utilized and the difficulties the scientists faced during the period of their discoveries. All units will include laboratory experiences, discussion based lectures, and conferences on the culture to give each student a well-rounded understanding of the topics being presented to them.

The lab experience is a crucial aspect of this course because it develops students' critical thinking skills by encouraging bottom-up processing, the concept of creating an overarching idea by assembling several pieces of information. The students will not be entirely on their own to develop these ideas; there will be guiding questions and an end goal for each lab to ensure the lesson does not push beyond a student's abilities. The professor will encourage using creative strategies and decisions so that students create more than one possible explanation for what they are learning, and then show their reasoning for why they chose the explanation that made the most sense to them based on the accumulated information. These exercises will showcase the realistic development of scientific thought, which despite not always being correct, continues to advance scientific progress. Students will discover a concept from a specific time period, using only the background knowledge that they were given, before they have been introduced to all the relevant information from their lecture or conference. Within the paper *Making Biology Relevant to Students: Integrating History, and Context into College Biology*, the authors discuss how it is important to prevent students from criticizing previous experiments with their current day knowledge. They further explain that "when asking students to reflect on how these historical figures could have improved their experimental models, they must be reminded to stay true to the technologies and knowledge available at that point in time" (Chamany, Allen, & Tanner, 2008). Thus, in the lab it is necessary for the students to try to immerse themselves within the time period and refrain from using modern ideas so that they can get a sense of how it was for those scientists. Scientist rely on each other's information to continue refining theories. This point is enforced within the paper *How* Not *to Teach History in Science*. In it Allchin states "History thus shows how the process of science can sometimes lead to 'wrong' conclusions, while also leading to 'right' ideas" (Allchin, 2000). He suggests the importance of showing how ideas that were once thought to be right can later on prove to be wrong with further experimentation or vice versa. A wrong conclusion from one scientist can eventually lead to another uncovering a right idea. When a scientist comes to an incorrect interpretation of data, their research may still help further the entire community by providing valuable data that other scientists can use to draw their own conclusions. Students will gain understanding as to how this collaboration between scientists was crucial to creating some of the scientific ideas we have today.

In the conference section of the course, students will use cooperative learning by completing small projects with their classmates about the cultural on-goings of the period, so that students can understand how the scientific community was affected. They may do presentations, debates, discussions, or other activities that require interacting with their classmates to learn from each other. It will be an opportunity to enhance the lectures and labs by putting people, discoveries, and events in context of the time period. Topics students may focus on may include societal norms such as religious affiliations, another on politics, and another on economics. They may be portrayed through a specific event, object, or idea of the time period to give students something to focus on. The conferences would be especially applicable to this course, beyond the value of the topics, because science is an ongoing discussion in which ideas and opinions are often shaped by the input of the many members of the scientific community. The members of the class are going to shape the material they learn and the opinions they form.

4.2.3 WPI's educational values

WPI is known for its strong focus on project-based and hands-on learning experiences during a student's undergraduate career which is reflected in *A Statement of Values for Undergraduate Education at WPI*. Our proposed course, "Hands on History," intends to incorporate these values by strengthening students' potential as "effective thinkers and communicators" and their ability "to use evidence to present their ideas with logic, clarity, and persuasion." The *Statement of Values for Undergraduate Education at WPI* specifies that "programmatic breadth in general, and balance between technical and humanistic components in particular are the hallmarks of a WPI education. WPI's programs shall emphasize the scientific, technical, societal and humanistic contexts in which knowledge is applied and constructed. Education activities shall challenge students to make connections between disciplines, to consider multiple viewpoints and to appreciate the consequences of their actions" (Office of the Provost, 2013). This statement highlights two very important points – the necessity of knowledge to be "applied and constructed," as well as the need for students to understand the relevant contexts of this knowledge. When misconceptions become wide-spread and deeply ingrained among students, proving a thorough historic context may simply not be enough to implement a change and help students to fully grasp specific scientific events. Introducing a new course, which would engage students in a more extensive laboratory experience as well as have an interactive conference, would allow students to gain a better understanding of the scientific process by allowing knowledge to be acquired and enhanced through hands-on activities and group discussion, thus making newly learned information more comprehensive (Chi, Roscoe, Slotta, Roy, & Chase, 2012).

4.2.4 Objectives

The responses of students to preliminary trials conducted in existing history of sciences courses have clearly demonstrated a need for an expanded course. To address the limitations of the existing courses offered at WPI, four primary objectives were chosen to guide the design of the proposed course. The purpose of the objectives is to ensure that the innovative delivery of the new course and any suggested improvements are successful at addressing current needs and therefore are valuable to students' education.

1. To provide hands-on opportunities and to encourage students to be active in their own learning process by means of authentic laboratory work or simulations of past experiments.
    - To promote students' problem-solving ability, critical thinking skills and creativity
    - To promote students' understanding of why scientists conduct experiments
    - To provide students with a firmer foundation on which to base their own understanding of theory and scientific advance
2. To help students see science as the wonderfully many-sided human endeavor that it really is.
    - To show that scientific progress does not amount simply to a series of incidental discoveries but rather is characterized by feats of human ingenuity and creative thought
    - To provide students with opportunities to reflect on the complexity and excitement of scientific work
    - To convey the effect of social and cultural influences on science
    - To exemplify that flawed theories can lead to advances in scientific knowledge
3. To help students gain insight into the process behind scientific discoveries.
    - To demonstrate that the growth of knowledge is not nearly as simple as most science textbooks would have us believe

- To demonstrate that science is not necessarily a steady and cumulative progression toward the pinnacle of modern achievements
- To help students discover that science is not a set of facts but that theories change and that science does not have all the answers
- To show that there is no single scientific method but instead a complex mixture of goals, interests, and motives
- To stress the importance of recognizing mistakes and retesting of hypotheses
- To exemplify the role of external factors such as luck, the work of others, the materials and equipment available at the time

4. To help students draw connections between science and history as disciplines.
    - To help students recognize the value of cooperation between different areas of study.
    - To increase students' awareness of the very different ways of making sense of the world.

4.2.5 Applying educational psychology

The new course will be developed using theories and concepts from educational psychology in order to present information to students in a way they can benefit the most from. Activities, labs, and lectures will be designed based on theories from developmental, cognitive, social, and educational psychology such as those from the researchers Vygotsky and Freud. Different views of distinct pedagogies, both traditional styles and modern methods, for teaching the course will be addressed in order to determine how the psychological theories can be concretely applied to a classroom. Each unit modeled in this paper will have an explanation of why the proposed activity was designed specifically to maximize the educational value of the material and which theories were used to determine this. "When asking students to reflect on how these historical figures could have improved their experimental models, they must be reminded to stay true to the technologies and knowledge available at that point in time" (Chamany, Allen, & Tanner, 2008). The components of the course will develop chronologically, allowing the students to utilize the knowledge of previous discoveries in order to understand which tools and theories were available at the time. In the lab, students will discover a concept from a specific time period before they have been introduced to all the relevant information from their lecture or conference. This will allow students to develop problem-solving techniques and challenge them to think like the scientists of the time period who needed to piece existing knowledge together with the results of the experiments to draw new conclusions.

4.3 CONCLUSION

Having established the need for a new interdisciplinary course in the history of science, model units with innovative laboratory experiences and conference activities have been designed to serve as a basis for the entire course. These workable models are meant as examples to be used by professors for their own course design but their main purpose is to serve as a "proof of concept" for the interdisciplinary course as a whole. These models can be modified to fit different class schedules and interests of both professors and students. The units have been designed with the aforementioned objectives in mind and are rooted in the principles of educational psychology outlined below.

5 MATERIALS AND METHODS

5.1 MODEL UNIT

The motivation behind a hands-on history of science course stems from the increasing research which demonstrates that active learning is key to motivating students to learn (Frederick, 1993). Active learning puts students in control of their learning through a variety of activities including "clickers," cooperative group activities, labs, etc. The opposite of this is passive learning which can be thought of as students observing a lecture in order to gain the material for the course (Arnaud, 2014). However, in order for active learning activities to be effective, they must be carefully designed and based on research in the area of education psychology (Deslauriers, 2011). To facilitate the proper use of these activities, traditional pedagogical methods in science and history will be reviewed, and compared to the increasingly accepted and novel pedagogies in those fields. The literature on combining multiple areas of study will be reviewed. Subsequently, each component of the model unit suggested for a hands-on history class will be analyzed by their expected benefits and costs. This literature review will not only facilitate the development of an effective model unit, but also aid professors who are looking to design a similar course on their own.

Two pedagogical models aim to teach students history in different ways. The older, traditional model, called the "coverage" model, uses various texts and lectures to provide students with as much material about the huge history discipline as possible. This approach assumes students are going to absorb the material given to them. The point is to provide the students with information, which they are then responsible for, regardless of its presentation or the students' abilities to analyze the information. Alternatively, Lendol Calder, a history professor, proposed an alternative to the traditional model with his own "uncoverage" model. He disapproved of the coverage model because it did not teach students how to use the tools in the field of history before expecting them to understand and value the facts learned (Sipress & Voelker, 2009). Similarly, Charles G. Sellers, a historian and professor at University of California, Berkeley said, "The notion that students must first be given facts and then at some distant time in the future will "think" about them is both a cover-up and a perversion of pedagogy. . . . One does not collect facts he does not need, hang on to them, and then stumble across the propitious moment to use them. One is first perplexed by a problem and then makes use of facts to achieve a solution." The coverage model also encourages the misconceptions that students can have about history, whereas the uncoverage model addresses them. For example, if they are presented with conflicting accounts of a situation, then one must be true and the other must be false, instead of realizing that they are both true, but coming from sides with different perspectives, experiences, and information. Calder suggests teaching students to develop skills of inquiry, perspective, comparison, acknowledgment of the unknown information, and understanding that the field of history is constantly changing and developing (Calder, 2006). Until students have these basic skills and concepts, they will have difficulty understanding the facts they learn about a time period and trying to organize those facts into cohesive ideas. There is minimal research in cognitive psychology that supports the first method, while the second method is backed by continually increasing research. This course aims to incorporate the second methodology in a way that can enhance the understanding of the history and development of science.

The idea of incorporating history into a science course may well seem like it would take up more time resulting in the loss of the scientific material of a course, however, literature suggests that combining two fields actually benefit each other in terms of understanding of the material and enhances the usefulness of each area. As Jeffrey Wadsworth, director of the Oak Ridge National Laboratory says, "One of the things that I have observed is how increasingly the fields of sociology, bioethics, and economics are necessary to execute our missions in the apparently harder sciences as we move ahead (Committee on Facilitating Interdisciplinary Research, 2004)." We live in a world where science and technology is necessary for the advancement of the humanities and social sciences, and vice versa. It then makes sense that in order to prepare a workforce for that world, that their courses are integrative. For example, politicians who can draw on a biology background, will have a better understanding of how laws dealing with health and medicine. Another example is that computer scientists often have coworkers with a wide range of cultural backgrounds because their work can often be done over long distances. Each of these cultures has its own view on work ethic and criticism, which needs to be taken into account when working in a group. These are just a couple examples of skills that integrated courses address (Chamany, Allen, & Tanner, 2008). Aside from the benefits in the workplace, the benefits to a student throughout their education are also important. A survey conducted on students who were double majoring and comparing them to those focusing on a single major, perceived double majors to have more creativity, and may have better problem solving and communication skills resulting from integrating their two majors. However, in this study, students said they often felt that the lack of course integration and teachers going outside their area of expertise made integrating their majors more difficult (Pitt & Tepper, 2012). Lastly, the quick-return benefits of integrative activities in the classroom include a better understanding of the material when it is put in context rather than activities that focus only on the topic of interest. When an integrative course was implemented at the University of Utah, students also reported higher interest levels in the course, and fewer people dropped out of the course than the norm for non-integrated courses (Dick, 1989). While the experimental research in this area is minimal, the body of literature promoting its implementation is too great to ignore. One needs to be careful to design proper activities for an integrated humanities and science course, which is the goal of this project.

The designed course will consist of lectures, conferences, and labs, each with their own focus and incorporating ideas in both science and history. While lecturing may appear to be a passive form of learning, there are many ways to make it interactive and it is the backbone of the course in terms of information about the discoveries learned in lab and the culture for the conferences. It is important that even though it is labeled as a lecture that teachers treat it as an opportunity to keep the students involved. The article "Interactive Lecturing: Strategies for Increasing Participation in Large Group Presentations" Argues that "educational research has shown that students who are involved in the learning activity will learn more than students who are passive recipients of knowledge." (Steinert & Snell, 1999). Asking students questions during lectures is a good way to help them develop problem solving skills, but the way they are asked can be even more important. In terms of Bloom's taxonomy, a way to develop assessments of student's knowledge in which achievement at higher levels demonstrate better learning of the material, a typical lecture can only cover the first two levels of knowledge and comprehension. Questions drawing on a combination of knowledge from readings, assignments, conferences, labs and lecture material ensure that students are not simply regurgitating the material, but pulling from multiple sources and incorporating it into their schema of the topic, which brings students to the fourth level: analysis (Krathwohl, 2002). An easy resource to facilitate participation in the lecture hall is to use "clickers" which allow all students to respond to a question by pressing a button corresponding to the answer. The computer then records each student's response and presents the results of the class. A teacher can then ask students to defend their answer. Clickers can be used to make sure that students don't sit back and let others answer questions, but that they at least attempt to answer every question. It also gives them an idea of where they need improvement in the class (Shieh, 2009). A company that WPI uses for this technology is Turning Technology. Under the uncoverage model, if students are not only learning facts in the lecture hall, but also learning how to use those facts and incorporate them into other settings than the classroom, then they will be less likely to forget them.

The laboratory component plays an essential role in the learning experience of the students. In fact, the implementation of a lab experience encourages the students' use of critical thinking and problem solving skills. Unlike typical lab experiences, each unit within the course will include a lab that introduces the participants to a set of problems and activities that will lead them to discover the intended concept. Students will be able to interpret what they are learning for themselves instead of being given the answer. Also, instead of already knowing the discovery made from the experiment and how the theory works prior conducting experiments, the students will only be given details and instructions which are crucial to conducting the experiment so that they can make their own discoveries. The most common lab activities that are used are considered "cookbook" labs in which students are provided with step-by-step instructions on how to complete a lab, with some questions based on their observations and calculations. While in some cases, such as learning a specific technique or learning to use an instrument, cookbook labs are necessary, they don't teach require critical thinking. The more involvement the student has in developing their procedure and interpreting the results, the more they will understand the material presented (Gooding & Metz, 2012). One study found that when inquiry labs were used in place of traditional labs, students had a better "scientific attitudes" which were measured based on areas such as curiosity, open mindedness, suspended judgment, and persistence (Khan, 2012). These attitudes are beneficial for history, science, and learning in general, and are some of the qualities that this course would like to encourage.

An essential aspect of inquiry labs is the idea of problem-based learning, which as explained in the article Problem-Based Learning, an effective way of teaching students to "think critically and logically about what they believe to be true, and, perhaps most importantly, to base their understanding on evidence" is to apply problem-based learning (PBL) to the classroom (Metz, 2006). Through this article, the author is relaying his belief that the PBL approach will benefit the student's learning experience and teach them critical skills. Steve Metz then suggests how this method can best be applied when he states "In the best PBL scenarios, constructivist learning is driven by challenging, open-ended problems; students work in collaborative groups and teachers become facilitators." Essentially he is explaining that problem-based learning is most effective when students work in groups and the teachers take more of a helping and overseeing role instead of telling them exactly what they should do to get the right answer. This concept is also touched upon in the book Foundations of Problem-Based Learning, which explores the concept of problem-based learning and how it can be used. At one point, the authors relate problem-based learning to Vygotsky's theory of the Zone of Proximal Development. They explain that Vygotsky's theory "suggests that learners have limited capabilities for learning beyond their current level. Thus effective learning can be reached by providing sufficient challenge without going beyond the learner's capabilities." (Savin-Baden & Major, 2004). Overall, the theory proposed by Vygotsky viewed the place where enough challenge is given to encourage learning, but not overwhelm the person as the "optimal zone." The authors formally concluded "in problem-based learning with an experienced facilitator to guide the process and collaboration with peers, a student's optimal zone is extended." Essentially the idea of supplying guidance to the student through their discoveries allows the zone in which they are capable of learning to expand and more understanding is achieved.

In addition to this, concluded in the article Vygotsky's Zone of Proximal Development and Problem-based Learning: Linking a theoretical concept with practice through action research, "Embedded in Vygotsky's social constructivist view of development is the idea that learning is the outcome of collaborative problem-solving, and that it is best facilitated through the use of whole and authentic activities." (Harland, 2003). The implementation of a laboratory experience will provide the students with the authentic activities they need in order optimize their learning through problem-solving. Thus, the proposed laboratory section of the course will encourage teachers as facilitators in order to help the students proceed in the right direction when conducting their experiments. This scaffolding approach will increase the student's ability to understand what they are learning in the laboratory, while still allowing them to discover the solutions they are striving toward by themselves. The importance of scaffolding is discussed in the journal article "Scaffolding complex learning: The mechanisms of structuring and problematizing student work." The author states, "The idea of scaffolding is now in increasing use in educational design. In these contexts, the intention is that the support not only assists learners in accomplishing tasks but also enables them to learn from the experience." (Reiser, 2004). Scaffolding used throughout the laboratory will allow the students to learn through their own discoveries, but will also provide them with an option for help if they need assistance. Overall, the labs would promote a more realistic experience of the world in which scientists work and how science advances.

Another aspect of each unit will be the use of conferences and discussion-based lectures. The conference section will focus on the cultural background of the unit's discovery. During each conference, the students will be split up into groups and then each person will be given a certain topic to research. These can range from the politics of the time to the societal norms. Then, each student will be become an "expert" on their topic. Once this is done, the students with the same topics will meet and discuss what they have learned and increase each other's knowledge. After, the original groups will meet and each student will present what they have discovered on their research topic. The learning goal of these conferences are to help the students connect the scientific world to the history surrounding a discovery; hopefully this will help them remember and understand the material by putting their learning in context, while also helping them develop good research and communication skills.

This style is a form of jigsaw learning not only encourages cooperative learning, but also enables discussion among students. Cooperative learning includes a variety of exercises in which students are using each other as resources for information, ideas, and questions in order for everyone to better understand the material. As discussed in the article A "Jigsaw Classroom" Technique for Undergraduate Statistics Courses, student achievement can benefit from cooperative learning. The authors state that "having one or more partners may bring increased individual attention to a less able student, beyond what the instructor is able to provide." (Perkins & Saris, 2001). Even though the article is specifically about how the jigsaw method benefitted a statistics class, the statement explaining how students can actually learn from one another and enable the learning of each other can be applied to most, if not all, classes. A students' ability and capacity for learning can be improved in any course in the same manner as it was in the statistics course. Furthermore, the encouragement of cooperative learning and the jigsaw method is explained in the article "Group Scribbles to Support Knowledge Building in Jigsaw Method." This article is about a study that was conducted on the use of a program called Group Scribbles and how it affected understanding achieved during jigsaw cooperative learning. Within the article, the authors explain that "when correctly implemented, cooperative learning improves information acquisition and retention, higher-level thinking skills, interpersonal and communication skills, and self-confidence." (Looi, Lin, & Liu, 2008). Basically, this point in the article elaborates the multiple benefits of working in groups and learning from each other. Students tend to increase their abilities to retrieve information, retain that information, relate it to their peers, and be confident while doing so.

5.2 Proposed Unit

5.2.1 Astronomy unit

Each activity of the fully designed and implemented unit had plenty of consideration put into it before being implemented in the testing of it. Resources used to develop these activities included input from students in past history of science courses, our own input as students, input from professors including our project advisors and the teacher allowing us to use his class as a guinea pig, and most importantly, the research the model unit was designed from. The following sections provide justifications for each activity in order to provide an understanding of why it was designed in the way it was and as an aid for the designing of other units.

Lecture topics have been included in Appendix # for the instructor to reference. Ideally each lecture would include active participation from the students through systems such as "clicker questions" which is currently used by many courses at WPI, however, infrequently in the history courses. WPI currently uses a company called Turning Point Technologies as a provider for these clickers. We have included some example questions that might be good for to use. These questions require that all students answer using a device or the internet during the class period to make sure that they are paying attention during a lecture period and contributing to the class. The questions not only reflect what they are learning in the lecture, but also an opportunity to connect it to their readings and assignments. Other ways to make the lectures more memorable would be to include videos that students could watch as they are filing into class. These videos would relate the material they are learning about to current day topics or culture references. For example, in the astronomy unit, an included video might be a trailer for a popular movie like The Space Odyssey and then a quick discussion about how astronomy has developed into popular scientific fiction stories. Finally, a suggested reading assignment was chosen based on the topics within in relation to the lecture material.

Many laboratory courses at WPI require students to complete a pre-lab assignment to ensure they have all the necessary information to participate and complete the lab correctly. While this is helpful to make students understand the concepts being taught in the lab, it often does not accurately portray how a true laboratory experience would occur. In order to mimic the discovery of the telescopes as accurately as possible and get students situated in the time period of the discovery, the pre-lab assignment for this unit focused on setting up the knowledge the scientists had available to them beforehand and the reasons behind their studying the topic. The students are questioned about the process of glass-blowing, the already widespread uses of lenses before telescopes, and the goals of parties other than scientists who might be interested in such a device. Although the designed lab also covered Newton, the focus of the lab was on Galileo's discovery, and as such, the pre-lab assignment only covered Galileo because the students had covered that time period in class already, but had not moved beyond it to Newton's time period. The other goal of this assignment was to provide material that could promote discussion during the lab activity by hopefully sparking an interest in the subject by assigning importance to the material.

The laboratory experiment was adapted from the Outreach ToolKit Manual created by the Astronomical Society of the Pacific provided by NASA. The original experiment was designed to be achievable by children, however, it was modified to be more thought-provoking in order to achieve the goals needed and raise it to a freshman college level. To do this, the lab includes several historical blurbs about how Galileo heard about the telescope idea, what drove him to persevere it, and his achievements and mistakes along the way. This is to make sure that the students were continually put in his mindset of the researcher and time period throughout the class. The lab was also modified by turning almost all the directions into questions that would guide the students through the lab rather than instructing them all the way through it, and were probably similar to the type of questions Galileo and Newton would have used to direct their research goals each day. This lets the students make mistakes along the way, however, the questions are directed enough that if they started going in the wrong direction that they would hopefully notice and go back to readdress their thought processes. There were a few minimal directions in order to make sure the equipment wouldn't break, or that the students would be able complete the lab in the class period. We also designed the lab itself to have the possibility of modification, for example, if a professor was unable to have a long lab period for the students to use every week then they could remove the entire Newtonian telescope lab activity and still reach the intended goals. A post-lab assignment was designed for the students to complete by a week after the lab which just addressed the students' comprehension of the scientific design process, and helped them look beyond this discovery to its implications further in time.

The primary goal of the printing press discussion was to teach students about the culture of the Galileo's time, and how the culture affected the scientific community. The assignment required the students to research how an invention, the printing press, changed the culture in order to link the important information to a physical idea that they could more easily remember. The students taught each other the material using jigsaw learning, in which every group was responsible for the success of the class so that they could appropriately understand about how the culture affected the scientific community and more specifically Galileo, and write a short paper about their conclusions. This activity required that they work as a community rather than as individuals in order to achieve a common goal, and to do valid research using primary and secondary sources which are valuable skills for one to utilize in science, history, and daily life.

This designed unit was tested in a current course at WPI: History of the Exact Sciences. Some of the materials needed modifications, as was expected would be necessary to fit into any already established course (see Appendix B for a complete overview of the proposed unit). The implementation of the course included surveys and testing throughout in order to assess the unit's feasibility and implementation which will be discussed later in this paper (see Appendix C for a complete overview of the implemented unit).

5.2.2 Anatomy unit

The anatomy unit has been designed as an example to help professors design their own units. This outline is simpler than the astronomy unit to help the professor build the unit into their own curriculum. The outline for this unit is listed in Appendix D. We have included examples of lecture topics in a moderately detailed outline. Along with the detailed lecture outline we have included suggested topics for further lecturing. The lectures topics we highlighted are electricity and voltage, animal dissection and vivisection, action potentials, and excitation contraction coupling.

Along with the examples of topics to cover in lecture we have included suggestions for reading assignments. For out of class reading we suggest the book *Blood and Guts* by Roy Porter. This book is relatively low-cost and contains information about vivisection, dissection, and other topics covered in the suggested lecture materials. The educational objectives of this course design include an emphasis on the impact of culture on the advancement of science. The anatomy unit should include the reading of primary sources which the students can discuss in groups or as a class. Some suggested primary sources have been included in the outline. Primary sources are important to the structure of this course because they give the students an idea of the views of society at the time the research was conducted. It is important to understand the culture surrounding scientific inquiry because it often has an impact on the outcomes and conclusions.

We have also included a few suggested laboratory activities. The topics covered in lecture and the primary sources will impact the selection of a laboratory activity. We suggested activities that were related to muscles, such as chicken leg dissections, as well as electricity and voltage such as a frog leg dissection and sciatic nerve demonstration. We are hesitant to suggest the students conducting dissection as it may be off-putting to some students. However, we have also included suggestions for hands-on lab activities that do not involve dissection. It is important that the materials used to conduct the laboratory activities are historically accurate. The students should have a feel for what the scientists who originally studied this material were doing to convey a proper understanding of the process of discovery.

These suggested materials are to help the professor build their own unit. This outline is not a strict guideline but an example to be utilized appropriately. The professor who instructs the hands-on history of science course should have some freedom in their own unit design and not feel constrained by our suggestions. The professor should keep in mind the learning objectives and basic structure of a unit outlined in the model unit section of this paper.

5.3 Implemented unit at WPI

The model astronomy unit was implemented during the first half of WPI's History of the Exact Sciences course (HI 2352) taught by Professor David Spanagel. This course traditionally begins with the history of astronomy, which is why it was chosen for the testing of the developed unit. While the proposed model contains more materials, including carefully selected reading assignments and detailed lecture slides, not all components of the unit will be integrated. Specifically, only the laboratory activity on telescopes and the workshop on the printing press were tested. Since many of the materials described in our proposed unit are only a suggestion and may be altered based on professor's individual teaching style and the needs of the class, Professor Spanagel utilized his own pre-planned reading assignments, lecture materials, and primary source discussions in the teaching of HI 2352. By working closely with Professor Spanagel, we ensured that the material taught and the activities selected would be an accurate representation of our model unit and the learning objectives as set forth for the proposed course, and conversely, that our involvement in HI 2352 was not dissonant with the original course structure.

All activities and assignments to be implemented were thoroughly reviewed by and discussed with Professor Spanagel to ensure a seamless and appropriate integration into the course. For most class periods within the astronomy unit, members of our group were in attendance to make observations and take notes. The first activity was Professor Spanagel's primary source discussion on astronomy before the existence of telescopes, when the only tool available was one's eyes. We did not include this in our designed unit, but the idea came from Spanagel, and it was decided that it could be useful because units in the designed course might include something along the same lines and would be beneficial to include in our unit. The laboratory experience followed the discussion, and was facilitated by two of our group members to further our understanding of the possible flaws and educational strengths of the designed lab. One group of students was be videotaped at their consent to reference later. Students were expected to complete and hand in a pre-lab assignment at the beginning of the class period, attend the lab session and fully engage in the activity, and then complete a post-lab assignment to be turned in the next day. Lastly, in the workshop on the printing press, small groups of students came prepared with a mini-lesson, in a format of their choice, to teach the rest of their classmates about the culture surrounding the use of the printing press. Originally the assignment required that each student write a short paper utilizing the knowledge gained from the workshop presentations to address how the culture affected the progress of science before, after, or during the time of its invention. This was modified by providing them with a few guiding questions to be discussed after the presentations, and then only one long paper was written for the entire group about their discussion. In order to assess each student's retained knowledge, there were a few questions on the midterm requiring a description of a key topic addressed in the unit, such as "refracting telescope," and an essay questions comparing Galileo to Herschell, another astronomer they learned about in lecture. All of the aforementioned activities will be assessed using grades on the assignments and feedback from the students.

From the beginning of the unit until the midterm, the students in the course were asked to complete a few optional surveys to get their opinions about the implementation of these activities. Data collected from surveys and grades was used to assess the viability, effectiveness, and popularity of the proposed course. To protect the identity of every student participating in HI 2352 and the testing of this unit, each student was randomly assigned a code on the first day of class. The only parties who knew the code were the individual students and Professor Spanagel since he needed it for grading purposes. This code enables us to track the progress and feedback of each student throughout the course while keeping their identity completely anonymous. The data collected from testing the model unit in HI 2352 would suggest whether the integrated hands-on and cooperative activities create a more effective, interdisciplinary course to teach students about the history of scientific progress. On the first day, they responded to a few questions on their understanding of the process of scientific discovery before learning any material. Shortly after the lab, they were asked logistical questions about their experience which they indicated on a seven-point Likert scale or in the form of an open response while the class period was still fresh in their mind. The other activities included similar questions as needed. After the midterm, students will be asked to complete a final survey about the overall unit and the activities included in it to determine their opinions about its effectiveness in teaching course objectives, the appeal of a laboratory-based history class, and other topics. This survey concluded our involvement in the History of the Exact Sciences course. We developed a preliminary analysis based on the quantitative data collected from the grades of the completed assignments and answers to survey questions, as well as the qualitative data from observations of activities, written answers on the homework assignments, and answers to survey questions. This analysis serves as the basis for determining if the demand is high enough among the students to consider implementing the proposed course, and if the activities showed to be a more educationally beneficial experience to the students than standard lecture-style classes.

6 RESULTS AND ANALYSIS

6.1 TESTING A UNIT

6.1.1 Preliminary Survey

The responses provided by students from the survey on the first day of class in HI 2352 confirmed our suspicions that many students have a narrow view of the world of science. In fact, it almost appears as though they think it has its own world, rather than being fully integrated into the rest of our society, or even that it is entirely contained in the individual mind of a scientist. When students were asked about the process of scientific discovery, 17 of the 25 students mentioned some form of the scientific method. While it is a valuable tool, it does not fully represent what scientific progress entails. Only one student mentioned how culture or other aspects of the world aside from science affect its development. He stated, "… their experiments and continually revised hypotheses may lead to a discovery in that field. It may be systematic or by chance." This student allowed luck to be a factor in the ability to uncover new knowledge. Only two students stated that a discovery must be accepted at least by the scientific community, but did not mention any social or cultural aspects of acceptance or lack thereof. Others mentioned how the research of other scientists can aid one's own research, which in turn can fuel the research of more scientists.

This shows that some students have a basic understand that science does not develop in sudden bursts of ingenuity, but rather in small ideas that gradually accumulate to reach a new insight. One student wrote, “[Scientific discovery] entails many things: first, a reason to do research, a motivation, then research in what has been done, finally the discovery after a lot of time commitment.” This student was confident in the optimistic, however, not necessarily true idea that if one puts in enough effort, eventually it will yield new breakthroughs. Science involves a multitude of incorrect assumptions and faulty experiments, which could hinder scientific advancement, but might help just as well. Interestingly, these responses were consistent between all students regardless of their level of exposure to history, science, or other humanities courses. However, based on what typical education system ingrains in students, these findings are hardly surprising. Overall, responses provided by the preliminary survey set a good baseline for designing the integrated science and history course with the goal of providing students with a more wholesome view of science.

6.1.2 Pre-Lab Assignment

The pre-lab assignment was designed to prepare students for the lab. Since the students did not know what the procedure was for the lab until they arrived the pre-lab was set up to get students thinking about the right topics without telling them what they would be doing. Some students walked in on the day of lab and said to their group members “I think we are building a telescope.” This indicates that the pre-lab got some of the students thinking about the correct subjects without telling them all what they would be doing. Many of the questions in the pre-lab included culture context, such as glass blow and widespread use of lenses. There were also questions asking students to identify uses of a telescope besides looking at a night sky. This question helped set historical context for the advancement of the telescope. Overall the pre-lab seems to have accomplished the goal we set forth for it.

Other unit designs should include pre-lab assignments designed with the same purpose. This pre-lab assignment would work well as an example as it got the students thinking the way we wanted it to. The pre-lab assignment should also remind students to think about the culture of the time period of the experiment. The laboratory activities help students to understand the process of scientific discovery and inquiry. It is more effective at this if the students are thinking about the correct time period and cultural prior to coming to the lab which can then be reinforced during the laboratory activity. The designed pre-lab assignment accomplishes all of the objectives we had set forth for it.

6.1.3 Primary Source Group Discussion

During the portion of Professor Spanagel's History of the Exact Science course the students were instructed to form groups of around four to five members. This was the first group discussion the groups had done together. In the early stages of the discussion some groups had a strong focus in communication between members while others seem to be focused on individual research for the beginning of the discussion. As a whole the students seemed to remain quiet and not fully engaged in the discussions right off the bat. After this initial difficulty starting the discussion wore off the group members seem to build well off of each other and began generating strong points of interest or of importance. The students in the groups were filling in the gaps in each other's knowledge. A student in Group B began a discussion with a question, "how did Ptolemy even think of the possibility that stars and planets move in a non-circular motion?" This was a fantastic question that produced a full group discussion with many of the students proposing their own ideas. This style of conversation eventually carried throughout the discussion as they continued to infer the thinking of the scientists and thinkers of the time in order to help them understand why they performed experiments and the reason for the way they did them. This type of discussion was able to strongly encourage every group member's participation and help each student understand the material better. In small group discussions students were willing to give answers they were unsure of. This is something that students don't do often in larger groups. In observing these student groups it was noted that students seemed able to put together the puzzle pieces that represented their own research to show the whole picture.

6.1.4 Laboratory Activity Observations

The following class the student groups were asked to participate in a lab that involved hands on learning and group collaboration. Their task was to complete a basic Galilean telescope and Newtonian telescopes using different sizes of lenses and mirrors, with little instruction on how to achieve these tasks. The goal of the experiment was to observe how the different groups would apply what they had learned and read about the topics and promote ideas and build off each to finish the telescopes by the end of class.

After having been given the materials and a few brief instructions the students split into their groups from the previous lecture and began flipping through the provided lab procedure. Observations toward the beginning of the lab many of the groups had a clear leader emerged amongst them. Across many of the groups it appeared that with one person taking charge other members of the group only participated when needed and did not go out of their way to add to the discussion. Many of the students seemed bored at the beginning of the lab although seemed to get more involved as the lab progressed. This suggested that we may want to include more parts to the lab early on to help get more students involved early.

Observations of Group 3 showed good communication right away, taking turns looking through the different lenses and explaining what they were seeing to the other group members. This early communication allowed the group to notice the difference between the convex and concave lenses and that they flip the image, although there appeared to no awareness to the significance of these observations. Early observations in Group 4 showed that this group was more focused on answering the questions from the lab rather than performing and understanding key concepts. After some time had passed during the lab Group 3 began to have 3 out of the 5 members highly engaged in the lab and the other 2 observing and making their own conclusions but not contributing highly to the overall discussion. This was evident during the lab one student notices the flipped image of the star on the screen and connects this to an earlier observation and this lead into a large debate on why the lens would flip the image. However, the group did try to involve everyone and plan out each step of the lab as a group rather than a few individuals perform the lab themselves. Contrary to Group 3, Group 4 is methodical in their planning of each step of the lab; thoroughly reading through the procedure before each step. Observations of this group show signs of individual thinking and observations. They did not show much group collaboration. They also appeared to follow a step from the procedure, get a result, and then start over again. This may have resulted in this group lagging behind other groups. For instance, while others are observing the image through the lenses and discussing how to move and change out the lenses this group has yet to place a lens on the meter sticks and line up the flashlight properly. After some guidance the group appears to understand key concepts that were missing before and moves right along through the lab.

Overall, we would consider the test lab a success with many good observations and points of concern made. This test class has successfully shown that a course taught in this style is a useful technique and can promote understanding a growth in the students involved. One great example of how well this style of teaching works was during the lab when one student noted that a, "bigger lens is brighter, does that mean it gathers more light?" This type of observation promoted thinking outside of the realm of the lab and added to the discussion. This became a perfect segway into the portion of the procedure that gives the example of how the human eye absorbs light and the reason for pupil dilation. This realization was a great discovery for the group and was able to bring home a many of the key concepts of the lab.

6.1.5 Laboratory Activity Worksheet

During the laboratory portion of Professor Spanagel's History of the Exact Sciences course the students answered questions pertaining to the lab and made sketches of their rudimentary telescopes. In order to assess the students understanding of the instructions and the material covered in the laboratory activity we collected their answers to the questions asked in the lab. This included simple questions such as observations on the difference in magnification between two lenses as well as drawings of the student telescope set ups. By reviewing these answers we were able to determine which topics covered in the lab were well understood by the students and which topics students seemed to struggle with.

While evaluating the students' drawings of the telescope we noted that some of the set ups were quite different from what was expected. The directions in the lab clearly state that the Newtonian telescope should be designed without angling the meter stick; however, at least 2 groups angled the meter stick as well as the flat mirror in order to reflect the image to the objective lens. This is an issue that we believed had been addressed but it might be necessary to include additional clarification. Students also had trouble deciding where to place the objective lens. Although the majority of students placed the objective lens in the right place some groups put the objective lens between the flat mirror and the flashlight. This is the portion of the lab we expected students to have difficulty with. They were given minimal guidance during this last part of the lab because it was not essential that they complete it. It is our belief that by failing to complete the last portion of the lab it might help to reinforce the idea that a success in a scientific setting may include learning what not to do.

There were a few other anomalies noted. One of these focused on focal lengths. When the meter sticks are first set up with the large lens and a smaller lens the students are asked to determine the focal lengths of both lenses. The majority of groups determined the same focal length for both of these lenses. Two of the groups found different lengths for the two lenses. Interestingly the both decided that the focal length for the larger lens was 1.5cm longer than the focal length of the smaller lens. This may be due to the differential light gathering between the two lenses or the difficulty in pinpointing the exact focal length. A difference of 1.5cm is less than 10% error and may not be a major mistake. There were other minor mistakes made by only a few people; improperly observed by convexity of the lenses, improper spacing of the lenses, and other similar minor mistakes. We believe the presence of minor difficulties to be consistent with work of appropriate difficulty. One suggestion we made based on the observations from these lab notes is the inclusion of correct diagrams for both telescopes in a lecture following the lab.

6.1.6 Post-Lab Survey

After completing the lab each of the students took a three question survey evaluating the lab. The second question asked if there was enough time to complete the assignment, 5 of the students said no. The students were also asked if the lab instructions were adequate. They answered on a scale of 1-7 with 1 being guided me step by step and 7 being left me in the dark. The average of the answers was 3.16. This is a good number because we did not want to be guiding the students through the lab but we did not want them to be lost. This indicates the laboratory was appropriate for the course it was being implemented into. It fit with the material being covered, gave the students an understanding of the scientist's experience, it fit in the time allowed, and the instructions were appropriate. Therefore, this procedure works well as an example to a professor designing new units.

6.1.7 Post-Lab Assignment

The post-lab assignment asked the students to think about what they had done. It forced the students to recap what they had accomplished and what they had failed to accomplish in the lab. The students were encouraged to use drawings of their telescopes to explain what happened in the lab. The only "thought-provoking" question asked in the post-lab assignment asked about flipping the image so it is no longer upside-down. We suggest adding more thought provoking questions, or questions that relate the lab to what is being covered in lecture. This will reinforce concepts in the lab as well as the concepts covered in lecture. Without more conceptual, thought-provoking questions the students will simply be doing busy-work and that does not fit with the design and objectives of the hands-on history of science course.

6.1.8 Printing Press Workshop

The students of the history course were ask to prepare presentations on topics relating to the same time period. The presentations were prepared within the same groups that the students worked in for previous activities such as the lab and the first discussion. These presentations and ensuing discussions were based on our cultural conference from the model unit.

The students were asked to make 4-6 minute presentations to introduce their topic to the rest of the class. The day of the presentations Professor Spanagel told the students they were going to discuss the topics from the presentations after and he advised them to take notes during the presentations to aid them in their discussions.

Once the presentations were completed the students remained in there groups and began to discuss their thoughts on the presentations. These discussions were done based on guiding questions provided by Professor Spanagel. The first discussion point was the most important impact provided by the printing press. The observed groups had difficulty deciding on a single most important point. They each brought up their own points. These points included: increased literacy, legibility, better translation, impact on science, and the emergence of cultural centers. The point of this is that each advancement allows for advancements in a lot of other fields. The impact in one field can spread through others.

The students were then asked to discuss what doubts they had about the information provided during the presentations. This is an important point because in order for jigsaw learning to work properly the individuals must trust the information provided by their peers. The groups observed did not bring up any serious doubts. There were a few concerns voiced such as the accuracy of literacy statistics or the timeframe involved with the printing presses impact on other cultural aspects. This is a good sign as it indicates the students trust one another’s ability to research and present accurate information. This is crucial to the process of jigsaw learning.

The last discussion prompt based on the presentations was the impact of the printing press and the topics in the presentations on the scientific community. The observed groups made note of a few important points; recorded history of science, spreading ideas, better communication, the ability to question existing knowledge, science is more accessible, and then presence of peer review. One important observation provided by a group was the following: "scientific advancement could become building off existing knowledge but it could also be the realization that existing theories are actually wrong."

The students continued their discussions by moving into other topics covered in the course. A few important observations were made during this portion of the course. The students have the ability to provide each other with the information needed based on simple prompts. The students also trust each other's ability to find and convey important information accurately. This evidence is important in supporting our suggestion to use jigsaw learning. Another important observation is the quote above about scientific advancement. This was a realization our group hoped students would learn throughout the designed course. The students in the trial course were able to make this observation in just a single unit.

The discussions of the observed groups, and the presentations both suggest that the activity was working as it should. This activity tested jig-saw learning, the idea that students working separately and then coming together can put together and learn more information than they would otherwise. The topics covered during the presentations were the ones we hoped to be covered when designing the topics. The first group researched the education system before mass produced books. This led them to discuss the rarity and cost of books, the difficulty of reading handwritten books, and the lack of books in school and religion. This overlapped with the second group's topic of literacy before and after the invention of the printing press. The second group taught the class that the printing press standardized text since it was no longer handwritten and that students found it easier to learn to read because books were now available in native languages. The other groups covered the topics of: the effect of the printed bible on religion, the effect of the printing press on the arts, printing businesses and the emergence of publishing, and the effect of the printing press on the economy. The students were able to draw connections between the culture of the time period and the changes in the science fields.

The topics covered were wide enough to provide a large scope of information but narrow enough to remain connected. This is important because it indicates the assignment is a good example for the design of future units for the course. The research the students conducted for this portion of the unit could have gone in very different directions. The students were able to take their prompts and research the topics we hoped they would with limited overlap amongst the presentations. The amount of overlap in content covered enabled the students to make connections between the topics without causing the students to sit through repetitive presentations. Our original design for this assignment did not include group discussion questions following the presentations. However, as a result of the group discussion questions we were able to observe the students thoughts on the presentations and get insight as to what they were taking away from the presentation day. This worked very well for observing the impact of the jig-saw learning as it showed what the students had learned from each other and not just from their own research.

6.1.9 Midterm Exam

Based on the results from the midterm exam in HI 2352, the activities showed increased learning of the material. The students' responses to the "identifications" were analyzed quantitatively by recording how many chose to respond to each question and what the average scores across the class were for those responses. As can be seen in Table 2, significantly more students chose to respond to the questions of the printing press, refracting telescope, and reflecting telescope which were related to the activities tested in the unit (47 responses) compared to the questions on irrational numbers, the Cartesian coordinate system, and longitude and latitude lines which were topic learned in lectures, readings, or typical discussions (33 responses). The average scores for the questions related to the activities that were experimental were also higher than the typical ones. The refracting telescope identification didn't even have a single person who lost points. When given the choice to write two essays out of three, 19 of the 20 students chose to compare Galileo and Hershel as one. The average grade for this exam was approximately 77%, a relatively high average. This data suggests that the hands-on and jigsaw learning activities helped the students learn and remember the material better than typical discussions or lectures.

Table 2

Results from HI 2352 Midterm Identification Questions

Identification	# of Responses	Average Score
Printing Press	19	84
Refracting Telescope	14	100
Reflecting Telescope	14	81
Irrational Numbers	14	77
Cartesian Coordinate System	12	79
Longitude and Latitude Lines	7	57

There were many points that students made in the essays that demonstrated a fuller understanding of the history of science. One student wrote about how scientists take other factors into consideration when deciding whether to pursue a study, such as money or advancement in their careers. He went on to say "The fact that what they were doing went against the contemporary beliefs is what makes their ideas so revolutionary and deserving of recognition." Other students wrote about how Herschel's past in music helped him through his connections with people who had the resources to support his research, and also presented him with challenges. One student even connected it to the present day when he wrote. "…composing music is no easy feat, but imagine the scientific community's reaction to Elton John announcing his discovery of another planet." One of the goals of this course is for students to see these scientists as real people, and not as saints in science, which this student has shown that he is beginning to connect with these scientists on a personal level.

6.1.10 Qualtrics Survey

Student reviews from the midterm online Qualtrics survey ranged from slightly negative to strongly positive. Students indicated on the Likert scales that they found both the telescope lab and printing press workshop to be educational and interesting compared to their normal learning materials, but neither was significantly more beneficial than the other. One quote from a student when asked to provide a theme learned from the lab was, "Theory and practice are very different. In practice, there are a lot more hiccups." This shows that students learned from the lab that experiments are not always as carefully laid out and performed as we try to make them. Other students seemed to isolate themes from the lab to only the time period of the inventor, instead of seeing how the trend continues today, which could be solved by changing the post-lab to a looking at a more current experiment and comparing the lab they did with the present day. When students were asked if lab courses would be valuable in other history courses an overwhelming majority indicated that they would find it beneficial to do so. The most important data came from the last question on the survey, which was a repeat of the question they were asked on the first day of class about what the process of scientific discovery involves. The differences were startling between the responses from before the course and after. One student's start of term response was, "Scientific discovery is all about trial and error. It's about experimenting with different theories to test the legitimacy of the idea. It also involves a lot of research into what has already been done in the field and using that to fuel your own work." At the end of the unit their response had changed to, “Scientific discovery involves getting your hands dirty; it involves experimenting and trying many different theories to try to get a result. Progress relies on people testing past ideas and conceptions and challenging them.” Although their response involves similar actions of experimentation and using previous knowledge, the tone of the response is more relevant to the view that science is not always just about the experimental method. Changes such as these occurred commonly throughout responses to these questions. Although only half the term was tested, the strong change in views of the students in only a few weeks suggests the materials used were highly beneficial additions to the course material.

7 DISCUSSION AND CONCLUSION

7.1 IMPLEMENTED UNIT AT WPI

The Hands on History of Science course was designed with four primary objectives in mind. Each objective was intended to address an important educational goal through integration of interactive course components.

The central component of the tested course was a hands-on laboratory period, during which students had a chance to become active in their learning process and explore the scientific method from different angles. The instructions for the lab were designed to serve as a guide instead of a step-by-step protocol in order to instill curiosity and inspire genuine scientific thinking. The challenges and questions posed in the lab also required students to be resourceful and to think “outside the box” by relying on other area of study in order to better interpret their findings in the field of astronomy. Students also learned that science is a human process through teamwork and collaboration. Our observations taken during the lab strongly suggest that students were using each other as resources and more importantly, were expanding upon each other’s ideas and thought processes in order to complete the lab. While their process was not perfect and their experiments were not without mistakes and sometimes biased interpretation of results, it is this experience that exemplifies science as a human endeavor. Students also benefited from being exposed to internal and external factors that affect the course of scientific progress. Students were often asked to recognize their mistakes and retest their hypothesis in order to make sense of their findings. Students also noted the benefit of having a group of students majoring in different fields and having a different knowledge base. Some of the group members also took note of how lucky they were when the experiment just happened to work on the very first trial. This arguably trivial experience illustrates an important component of scientific progress – scientific discoveries that involve chance circumstances.

In addition to implementing a hands-on learning exercise, students also participated in jigsaw learning through the Printing Press Workshop. This part of the unit was intended to enrich the educational development of students by asking them to participate in a group-effort research project. Students in each group had to conduct original research and prepare a presentation on a topic relating history and science. While the implementation of this section was not what was originally intended, and rather a mix of Professor Spanagel's normal way of teaching and our proposed workshop, students seemed to prefer to write about it most in the exam, and did better compared to the other identification topics. This suggests that something stimulated their interest in the subject matter and that they learned the material more in depth, although not as much as the lab helped their understanding of the material. It is unsure whether the method of jigsaw learning, the use of one topic to introduce the history of the time period, or connecting the science to the time period was the cause of this; however, it may be beneficial to incorporate more of these activities into the designed course than originally planned.

In order to understand the professor's side of this course, we asked Professor Spanagel to give us his opinion of how these activities affected the course. His response was the following:

> "The telescope "laboratory" activity was something completely different from any experience I have hitherto been able to provide to my history of science students, so I applaud and deeply thank your IQP group for dreaming it up for my class this term. The printing press small group research and presentations activity was the kind of thing that I do integrate into my classes from time to time, but I tend to assign this kind of activity much more frequently at the 3000-level than I do at the 2000-level. I think, on the whole, that both activities were constructive and effective ways of diversifying the instructional approaches offered in HI 2352. I remain very open to trying such initiatives for hands-on experiential learning opportunities again in the history of science courses yet to come (though the massive effort that your group invested into designing and delivering the lab

> experience gives me pause about committing to developing more such modules
> on my own from scratch)."

With this in mind, it seems that the laboratory activity was a success on everyone's part, but that work needs to be done to simplify the process by which the lab was created. This could be in part due to the lack of experience of our group with creating these activities in the past. Regardless of the problems of time for developing these activities, the outcome was well worth the work.

The unit outline was designed to be incorporated at any university or college. At WPI terms are seven weeks and students take three classes per term. This means that the students meet more often each week than they would at another university with 5-6 courses per semester. The organization of a unit is not based a weekly schedule which allows it to be implemented regardless of the number of course meetings per week. The course at WPI (History of Exact Sciences with Professor Spanagel) was used to test a sample unit. This course met twice each week for 1 hour and 50 minutes. This is a less common course schedule for WPI; however, the sample unit was easily adjusted to fit this format. In fact, this is a normal class schedule for a course which meets or a semester. This provides evidence that the units can be performed at other schools with different course meeting times than the normal WPI course.

Today students in college are told it may be difficult to find a job after graduation. The job market is highly competitive and therefore students should do their best to stand out. An important part of a good resume for a job or graduate school is to be a well-rounded student. This includes involvement with on-campus activities but also taking a variety of courses. An individual with a broader knowledge base will be more versatile and will likely be able to make a bigger impact in the work place. In order to establish a well-rounded student universities often have degree requirements that make students take courses in different areas of study. This includes students in science fields being required to take classes in the humanities fields like English or psychology as well as students in the humanities majors having to take a minimum number of science and mathematics courses.

As a specific example Worcester Polytechnic Institute requires that all of their students complete a minimum of 6 humanities courses including a practicum or seminar course as a capstone. WPI also requires the students to take courses in at least two different humanities such as English and history. This part of the humanities program is the breadth requirement. One of these two the students must focus on, this is called the depth requirement. The depth portion of the humanities requirement will include classes passed the introductory level as well as the humanities capstone. This multi-part humanities requirement for a degree from WPI forces students to take classes they may not normally sign up for. It ensures that WPI students have knowledge of topics and concepts outside of the STEM fields resulting in them having a broader knowledge base.

As an engineering school WPI focuses on getting students to take humanities courses. At liberal art schools this is much less of a problem because the students will be taking primarily humanities courses. The problem at these schools would be to push students toward STEM courses. The proposed hands on history course design helps address both situations. The hands on history course is an ideal solution for multiple reasons. It is designed to cover both STEM and humanities topics which provides students in either field to have an interest in something in the course. Motivated students are essential to a productive classroom atmosphere. As previously discussed the hands on aspect of the course is designed to engage students in a more complete manner as well as providing a concrete foundation for the concepts being taught in lecture. The culmination of these things; interested and motivated students and hands on learning, will address the aforementioned concerns in an all-around positive way.

7.2 FUTURE WORK AT WPI

As the design of the Hands on History of Science course continues there are a few suggestions for improvement from our team. From our observations of the implementation of the astronomy unit we have observed different levels of success from the different sections of the unit. We found the laboratory activity itself to be an effective teaching tool, an appropriate difficulty for the students, and also the right length for allotted time. However, we believe that some of the assignments with the lab should be modified. One of the changes we looked at first was the post lab assignment. The post lab assignment asked the students to recount how the major sections of the lab went. It also asked if there were any problems. These questions are important but not particularly thought-provoking. The suggested change is the development of thought provoking questions to further the objectives of the lab.

Our proposed unit design includes a section in which the students present on the impact of the printing press. Following the presentations we suggested that the students write individual write-ups based on the information in the presentations. During the course trial Professor Spanagel had his students discuss the presentations in groups. Using guiding questions they reviewed what they had learned and were forced to look for further implications of the information presented. The student groups then submitted a single paper based on the discussions they had. We believe that both of these methods have both good and bad aspects. We prefer the individual student write-ups because it requires the students think about what they learned in the classroom outside of the classroom. The idea of discussing within a small group does add an extra dimension to the learning experience and we believe this could be a positive change to our design.

Implementation of further unit testing is a strong possibility here at WPI. There are currently two professors that teach the majority of history of science courses. One of these professors, Professor Spanagel who assisted us in the testing of our astronomy unit told us he remained open to the idea of adding more of these activities to his classroom. "I think, on the whole, that both activities were constructive and effective ways of diversifying the instructional approaches offered in HI 2352. I remain very open to trying such initiatives for hands-on experiential learning opportunities again in the history of science courses yet to come" (Professor Spanagel, Personal Communication). It is important that the professors helping to implement these new activities and learning experiences are as enthusiastic as Professor Spanagel.

Professor Spanagel also said "the massive effort that your group invested into designing and delivering the lab experience gives me pause about committing to developing more such modules on my own from scratch." This quote told us that future work done by IQP groups should be focused on the building of potential units for a professor. We suggest having an IQP team that focuses on designing outline units that are similar to the astronomy of anatomy units we have outlined in the appendix. Working with Professor Clark and Professor Spanagel to establish appropriate topics to be tested in WPI classrooms will help the IQP group to narrow their focus. However, unit design should also include topics not already covered in the history classrooms here. As we have designed an in depth unit for astronomy we believe it would be appropriate for the next group to start by focusing on building units that can be implemented into the other history of science courses here at WPI such as the history of life sciences of the history of technology. We have a basic outline of an anatomy unit that could be expanded upon and be testing in the history of life sciences class in the future.

The unit outline was designed to be incorporated at any university or college. At WPI terms are seven weeks and students take three classes per term. This means that the students meet more often each week than they would at another university with 5-6 courses per semester. The organization of a unit is not based a weekly schedule which allows it to be implemented regardless of the number of course meetings per week. The course at WPI (History of Exact Sciences with Professor Spanagel) was used to test a sample unit. This course met twice each week for 1 hour and 50 minutes. This is a less common course schedule for WPI; however, the sample unit was easily adjusted to fit this format. In fact, this is a normal class schedule for a course which meets or a semester. This provides evidence that the units can be performed at other schools with different course meeting times than the normal WPI course.

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9 APPENDIX A: CURRENT COURSES OFFERED AT WPI

HI 1331. INTRODUCTION TO THE HISTORY OF SCIENCE
An introduction to the methods and source materials historians use to study the past, through the concentrated examination of selected case studies in the history of science. Possible topics include: contexts of scientific discovery, translation and transmission of scientific knowledge, revolutions in scientific belief and practice, non-western science, social consequences of science.

HI 1332. INTRODUCTION TO THE HISTORY OF TECHNOLOGY
An introduction to concepts of historical analysis — i.e. the nature and methodology of scholarly inquiry about the past — through the concentrated examination of selected case studies in the history of technology. Possible topics include: the influence of slavery on the development of technology in the ancient world and the middle ages; the power revolution of the middle ages; the causes of the industrial revolution in 18th-century Britain; and the emergence of science-based technology in 19th-century America.

HI 2331. SCIENCE, TECHNOLOGY, AND CULTURE INTHE EARLY AMERICAN REPUBLIC
This course surveys American science and technology from the first European explorations until the founding of WPI (in 1865). Topics may include: Enlightenment scientific theory and practice in colonial North America; Romanticism and the landscape; the politics of knowledge gained through contact with Native Americans; engineering and internal improvements; geography and resources in a continental empire; the American Industrial Revolution; the rise of science as a profession; the emergence of scientific racism; technology and the Civil War. This course will be offered in 2014-15 and in alternating years thereafter.

HI 2332. HISTORY OF MODERN AMERICAN SCIENCE AND TECHNOLOGY
This course surveys American science and technology from 1859 to the present. Topics may include: Darwinism and Social Darwinism; scientific education; positivism and the growth of the physical sciences; the new biology and medicine; conservation, the gospel of efficiency and progressivism; science, World War I and the 1920s; the intellectual migration and its influence; science technology and World War II; Big Science, the Cold War and responses to Big Science; and cultural responses to science and controversies about science.

HI 2352. HISTORY OF THE EXACT SCIENCES
This course surveys major developments in the global history of mathematics, astronomy, and cosmology, as manifestations of the human endeavor to understand our place in the universe. Topics may include: Ancient Greek, Ptolemaic, and Arabic knowledge systems; the Copernican Revolution; mathematical thinking and the Cartesian method; globalization of European power through the navigational sciences, applied mathematics, and Enlightenment geodesy; social consequences of probability and determinism in science; theoretical debates over the origins of the solar system and of the universe . This course will be offered in 2013-14 and in alternating years thereafter.

HI 2353. HISTORY OF THE LIFE SCIENCES
This course surveys major developments in the global history of biology, ecology, and medicine, as manifestations of the human endeavor to understand living organisms. Topics may include: Aristotelian biology, Galenic, Chinese, and Arabic medical traditions; Vesalius and the Renaissance; Linnaeus and Enlightenment natural history; Romantic biology and the Darwinian revolution; genetics from Mendel to the fruit fly; eugenics and racial theories as "applied" biology; modern medicine, disease, and public health; microbiology from the double helix to the Genome project; and the relationship of the science of ecology to evolving schools of environmental thought.

HI 2354. HISTORY OF THE PHYSICAL SCIENCES
This course surveys major developments in the global history of geology, physics, and chemistry, as manifestations of the human endeavor to understand time, space, and the rules that govern inorganic nature. Topics may include: ancient atomism; alchemy and magic; the mechanical philosophy of Galilean and Newtonian physics; Hutton and the earth as eternal machine; energy, forces, matter, and structure in 19th century physics and chemistry; radioactivity, relativity, and quantum theory; the plate tectonics revolution. This course will be offered in 2014-15 and in alternating years thereafter.

HI 2402. HISTORY OF EVOLUTIONARY THOUGHT
This course will trace the history of evolutionary thought, including the growth of the geological sciences and expanding concepts of geological time, increased global travel suggesting new perspectives on biogeography, discoveries of fossils of now-extinct animals, and developments in comparative embryology and anatomy, culminating in the synthesis effected in 1859 by Charles Darwin, and in the Modern Synthesis of the 1940s. It will include emphases on the relationships of evolutionary and religious thought, and on depictions of evolutionary themes in the larger culture, including the arts, film, literature and popular culture, and will examine controversies, including current controversies, over evolution and the teaching of evolution in public schools in the United States. This course will be offered in 2013-14 and in alternate years thereafter.

10 APPENDIX B: PROPOSED ASTRONOMY UNIT

The following document is the proposed version of the Astronomy Unit.

Table of Contents:

Astronomy Unit Lecture Presentation Outline and Suggested Readings:

- Suggested In-Class Videos
  - *2001: A Space Odyssey Trailer*
    - *http://youtu.be/2FhTgjYDe-4*
  - *Full Transit of Venus (All Wavelengths + Sonification)*
    - *http://youtu.be/urbTgl9jeNs*
- Suggested Assigned Reading
  - *Cooper, C. (2013). Our sun: Biography of a star Race Point Publishing.*
  - *Chapters: The Worship of Our Sun, The History of Our Sun*
- Beginning of Lecture –
  - Ancient astronomy in the form of astrology
  - Heliocentricity versus egocentricity
- Ancient Astronomy in different regions of the known world –
  - Mesopotamian Astronomy
    - Earliest civilizations known for observational astronomy
  - Babylonian Astronomy
    - Most prominent civilization in Mesopotamia for astronomy
    - Began as observational study applying to religion and calendars then becoming a mathematical theory
    - Earliest record keeping regarding astronomical observations
  - Egyptian Astronomy
    - Astronomy used to tell when to harvest and the different seasons
    - Major religious beliefs
      - Many gods and goddesses represented by constellations and astronomical bodies
    - Different calendars/clocks
      - Lunar calendar predicting Summer solstice and flooding of the Nile River
      - Switched to Solar calendar which is credited with current, modern calendar (did not include leap years however)
      - Used the stars to tell time during the night using 12 different star markers thus they are credited with coming up with the 24 hour clock
    - Monument construction
      - Tomb of Senmut depicted astronomical knowledge on ceiling, including planets and the star clock
      - Temples and pyramids oriented according to astronomy and cardinal directions
      - Airshafts are believed to be oriented toward the constellation Orion because it represents the god of death and afterlife
  - Chinese Astronomy
    - Known for having the longest continual history of astronomical observation, around 4000 years
    - Notable Observations –

        - Appearances and details of comets which were given divine interpretations of battle and other religious beliefs
        - Witnessing a supernova explosion in 1054 AD
      - Use of the lunar calendar based upon Jupiter's orbit
        - Each 12 year cycle associated with different animal based on location in the sky
      - "Mandate of Heaven" – kings and emperors used the sky for political advice and appointed astronomers to watch and interpret astronomical events
      - Dunhuang Star Atlas is the oldest known complete star map dating to around 650 AD pictures the northern sky with over 1300 stars and 257 star groups accurately
- Geocentricity – astronomical model in which Earth is the center of the Universe
  - Plato – 429-347 BCE (Athens)
    - Philosopher
    - Student of Socrates
    - States that the seemingly chaotic motions of the planets can be explained by uniform motions centered on the Earth
    - 2 sphere model
      - Stationary Earth
      - Moving sphere with 8 circles carrying 7 planets and fixed stars
  - Aristotle – 384-322 BCE (Ancient Greece)
    - Philosopher
    - Largest work in zoology during his time
      - Dividing into blooded and non-blooded categories
      - Closely related to vertebrate and invertebrate distinction
    - Believed the universe did not have a beginning or an end
    - Aristotle's Astronomy –
      - Proposed heavens were made of 55 concentric spheres
        - All celestial objects are on a sphere
        - Spheres rotate at different speeds
        - Fails to address that some objects seem to move closer and further away from Earth
      - Clicker Question:
        - Did Aristotle know that these problems were being ignored? Yes/No
      - Class Discussion Question:
        - If he did know that these problems existed why did he chose not to address them?
  - Hipparchus – 190-120 BCE (Alexandria)
    - Measured the distance to the moon during a solar eclipse
      - A total eclipse in Syene and a partial eclipse in Alexandria
      - Calculated distance based on angular difference and distance from two cities
  - Ptolemy – 90-168 CE (Alexandria)
    - Mathematician, astronomer, geographer

        - Placed the planets in a, order which remained until Heliocentric model
            - Moon, Mercury, Venus, Sun, Mars, Jupiter, Saturn, fixed stars
        - Proposed concept of equant
            - Circle around which a planet or center of an epicycle appears to move uniformly
            - Solves problem of retrograde motion and changing planetary brightness
    - Tycho Brahe – 1546-1601 (Denmark)
        - Observed supernova in 1572
            - Noticed that position did not change relative to other objects suggesting it was another star and not a local phenomenon
        - Observes a comet and calculates that it is further away than moon (corrects Aristotle)
            - Also noted that comet's orbit is non-circular thus suggests that other celestial bodies do no move in spheres
        - Based off observations of stars, assumes Earth must be center of universe and does not move
        - Proposed model that some planets orbit the sun as well
        - Class Discussion Question:
            - What is it about society that makes a scientist do this?
        - Clicker Question:
            - Is this sort of attitude preventing great minds from coming up with new, but possibly brilliant theories? Yes/No
- Geo-heliocentricity – Earth is stationary and the Sun and other objects orbit the Earth and some others orbit the Sun
    - The Church and Astronomy
        - Church generally supported astronomy
    - The Church and Geocentricity
        - God and heaven exist outside of the celestial sphere
        - Angels have power to control planet's movements
        - Earth is the center of the universe
- Heliocentricity – astronomical model in which the planets revolve around a relatively stationary sun
    - Philolaus – 470-385 BCE (Croton)
        - Philosopher and scientist
        - First to propose sun did not revolve around the Earth
        - Instead everything revolves around central fire
    - Aristarchus of Samos
        - First known model where Sun is at the center
        - Placed planets in correct order of distance from the sun
        - Used trigonometry to estimate distance to sun
        - Correctly identified the sun was bigger than the Earth and moon was smaller
        - His theories were often rejected for those of Aristotle and Ptolemy
    - Arabic and Middle Eastern Astronomy

    - Built first modern observatories funded by the governments to further education and research in astronomy
    - Detailed observations on calculations of orbits of planets and length of the year
- Copernicus
    - Started studying astronomy through his education into becoming a priest
    - Supports model of Heliocentricity with mathematical models
    - Begins "Copernican Revolution"
    - Assumptions of Copernican Theory-
        - There is no center of all celestial circles or spheres
        - The center of the universe is not the Earth, but only to gravity and the moon
        - All spheres revolve around the sun, therefore the sun is the center of the universe
        - Whatever motion appears in the heavens is a result of the Earth's motion, the Earth performs a complete rotation on a fixed pole in daily motion, while the heavens remain unchanged
        - The Earth rotates on its own axis but also revolves around the sun like any other planet
    - His work was originally accepted
    - Although once the Church realized that it meant the Earth is not the center of the universe, Copernicus was charged with heresy and forbid his book to be read or produced
    - Class Discussion Question:
        - Why would the church use Copernicus's calculations when they believed that the conclusions he made from using those calculations was wrong?
        - Did they believe that it was a mistake in thought that Copernicus had calculated correctly but interpreted incorrectly?
    - Many astronomers believe Copernicus' Theory but after conviction refuse to study it anymore
- Johannes Kepler – 1571-1630
    - Student of Tycho, but researched Copernicus and agreed
    - Also witnessed a supernova occur and last for 17 months
    - Determined ho light from the heavens entered the atmosphere and diffracted, also how it diffracted through lenses
    - His theory was condensed into Eponymos laws of planetary motion-
        - The orbit of every planet is an ellipse with the sun at one of two foci
        - A line joining a planet and the sun sweeps out equal areas during equal intervals of time
        - The square of the orbital period of a planet is proportional to the cube of the semi-major axis of its orbit
- Galileo Galilei
    - Fonder od Modern Mechanics and Experimental Physics
    - Developed the experimental method

        - Began disproving Aristotelian physics
        - Discovered the use of telescopes and quickly improved them to be 30x more powerful
        - His observations led to ideas of heliocentricity-
            - Spots on the sun
            - Mountains and “seas” on the moon
            - Milky Way made of many stars
            - Jupiter has moons
        - He could write about his discoveries and observations but could not write how this disproves Earth is the center of the universe
        - Eventually charged with heresy
        - Had to renounce his past work and the Copernican Theory and put under house arrest for life
        - Continued his work while under house arrest
- Edwin Hubble
    - In 1920 the Hubble telescope show us that we are just part of a galaxy of which there are billions more

De-identification Code ____ ____ ____ ____ ____
Date:

Pre-Lab Assignment

Instructions: Answer the following questions and hand them in at the beginning of class on Tuesday, March 25th. These questions are to be answered individually and may require some research. You do not need a bibliography but make sure the sources you use are credible.

1. Briefly explain the process of glass blowing as it was done in the 17th century.

2. How does glass blowing relate to astronomy and telescopes?

3. Widespread use of lenses came to Europe in the late 13th century, yet it took hundreds of years for the telescope to be invented. Why did it take so long? What factors could have caused the delay?

4. Before Galileo used telescopes to study extraterrestrial (meaning "in space") entities, they were used to view terrestrial (meaning "on Earth") objects from long distances.
    a. Give an example of when it would have been useful during the time period to see far away and the implications of this.

    b. Originally, Galileo did not refer to his invention as a "telescope". What term did he use and why do you think he named it such?

5. Galileo used lenses to invent the first telescope (specifically to look at the heavens), however he was not the first or last to use lenses. Name two other inventions that came before him and one that came after him. At least one invention must involve the use of two lenses.

De-identification Code ____ ____ ____ ____ ____
Date:

Lab Activity: Early Telescopes

Adapted from the Outreach ToolKit Manual, Astronomical Society of the Pacific

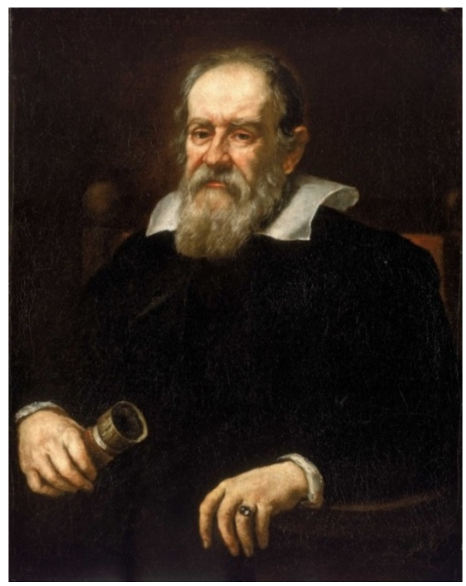
Instructions

**These instructions are only meant to be a basic guide and *not* step-by-step directions. This lab is meant to recreate the experience of Galileo and Newton in designing and improving telescopes. Try to think of this activity from the perspective of early scientists who did not necessarily know every step of the way but rather had to apply theoretical knowledge and work experimentally in a trial-and-error fashion. **

PART A: Galileo Galilei

History Lesson #1

Lenses were often used as reading glasses before the idea of combining them to create a stronger magnification. In 1608, Hans Lipperhey, a Dutch spectacle-maker in Middleburg, Holland applied for a patent for "a device to observe things at a distance." His application was denied on the grounds that, despite its usefulness, the design of the device was too simple to prevent others from discovering how to make it on their own accord. From the date recorded on the application, Hans Lipperhey is most often credited for inventing the telescope. However, many tradesmen were illiterate in the early 1600's and did not keep records, so it is difficult to determine if this was the true origin.



Portrait of Galileo Galilei, 1636.

By the spring of 1609, small, weak telescopes could be found in the shops of spectacle-makers in northern Europe, and the invention quickly traveled south to Italy. In Venice, Fra Pauolo Sarpi, a friend of Galileo, heard about the device and told his colleague. At the time, Galileo was only a mathematician, a role receiving less respect than most in academia. He was a very smart and well-known mathematician but he aspired to be a natural philosopher, one of the most respected fields, because of it consisted of studying the divine creation of our world, in an era where the church played a major role in daily life. Galileo saw the chance to create a high-quality "spyglass" to present as an asset to both the Italian government, and by using it to study the heavens in more detail than anyone previously, in order to gain respect as a natural philosopher.

Part 1

- Start out by looking at two smaller 50 mm diameter lenses over a piece of paper with a small font type.
- Do these both magnify the same?
- What do you notice about their physical properties?
- What connections can you make based on these findings?

!

Convex objects have an outward curving surface, whereas **concave** objects have an inward curving surface. The two lenses you have worked with are known as **double-convex** because they have two outward curving faces which makes them thicker in the middle and narrower at the edges.

Part 2

- Imagine having a clear flat piece of glass, like a window, between you and your partner. Would you be able to see him/her clearly? Next, carefully hold the stronger 50 mm diameter lens near your partner's face. How would this compare with the flat glass? Speculate how your findings can be explained in terms of physical properties and light interactions.

- To better illustrate light behavior, you are going to use the foam-and-sticks model.

- In this activity, each stick will represent the direction of a light ray. Push 5 sticks through the foam strip (no more than 0.5 in sticking out on the back side) such that they are parallel to each other and evenly spaced out. This setup is a representation of how the light rays travel through a flat glass.

- Now, slightly curve the foam toward the skewers such that they come to an intersection in the middle. This setup is a representation of how the light rays travel through a convex lens.

!

The phenomenon you just observed is known as **refraction**. Refraction occurs when a light ray changes its direction because it entered a different medium (which is easier or more difficult to travel through) causing its speed to change. In the case of the flat glass, where the glass medium has a consistent width, the light ray travels at a uniform speed with little to no change in direction. However, in the case with the convex lens, where the glass medium is inconsistent (thicker in the middle and thinner at the edges), the light ray no longer travels at a uniform speed and as a result, changes its direction.

Part 3

- Now, compare the weaker of the two 50 mm diameter lenses with the 75 mm diameter lens.

- Do these have the same magnification powers?

- What effect does the diameter have on magnification?

- Is the 75 mm diameter lens concave or convex?

- About 5-8 feet away from your table, set up a flashlight. This flashlight creates an image of a star which is going to represent the heavens.

From now on, all classroom lights must be off.

- Set up and secure two meter-sticks parallel to each other and with the scale facing up. Using appropriate fixtures, place the two lenses on adjacent meter-sticks. Secure a screen in front of the lenses. Make sure that the light beam is pointing directly toward the lenses and not angled in any direction. You may need to elevate the flashlight in order to accomplish this.

- Can you see the two fuzzy images of the star on the screen? How can you bring both of them into focus?

- After adjusting your setup to ensure that both images are in focus, measure the distance between each of the lenses and the screen.
- 50 mm diameter lens: ____________75 mm diameter lens: ____________

!

The shortest distance at which a lens can focus is known as the **focal distance**.
The sharp image of the star is created on the screen at the point at which all light rays passing through the lens converge. This point is known as the principal point of focus or simply, the **focal point**.

- Explain why the images go in and out of focus? Make a simple sketch of your setup, make sure to label all components (lens, light rays, screen, focal point, focal distance). Hint: Use the foam-and-sticks model if you are having difficulties visualizing this.

Sketch:

- Do you notice anything odd about the images being projected? Explain using your sketch.

- Compare the two images of the star. Is there a difference in their brightness? Do you think both lenses gather the same amount of light?

- Explain what accounts for these differences. Hint: Use the foam-and-sticks model to help you answer this question. Keep in mind that every stick represents a ray of light.

- Think about the pupils of your eyes. How much light do they gather compared to your two lenses?

- What happens to your pupils when you go into a dark room after being outside in the daylight?

!

When entering a dark room after being outside, your eyes adjust in order to collect more of what- little light there is in the dark room. Telescopes gather light in a similar way – as the opening (the lens) gets larger, the dimmer objects become easier to see. The opening through which light travels (i.e. the diameter of the telescope's lens) is known as the **aperture**.

History Lesson #2

Galileo spent months guessing and testing different lenses, because he did not have access to any of the designs from the tradesmen, until he finally created an instrument he deemed worthy. In the summer of 1609, Galileo had built his first telescope with a 3x magnification. He hit a road block when all the lenses he could acquire from local spectacle-makers were poor quality, and not the strengths needed, so he taught himself how to grind lenses. This was a process that takes many hours of concentration in order to perform correctly as there was no other way than to do it by hand. His telescope solved many issues previous telescopes had such as low brightness and poor clarity of the image. By the fall, he had a telescope of 8x magnification, which earned him the position of the Padua Chair of Mathematics. In November, he had a telescope with a magnification of 20x which he used to conduct most of his research in astronomy, and was the most powerful telescope available for the time period.

**Following in Galileo’s footsteps, you have successfully familiarized yourself with various lenses and their properties. Now, you are ready to put together a rudimentary telescope. **

Part 4

- Pick a lens which has the best light gathering abilities. This lens, called the “objective”, should be used to concentrate light into the image of the star.
- Pick a lens which can produce the best magnification. This lens, called the “magnifier” or the "eyepiece", should be used to make the image of the star bigger so that it could be observed in greater details.
- Using these two lenses and previously acquired knowledge, set up a rudimentary telescope on a single meter stick.
- Look through your telescope. What do you see?
- Make a sketch of your set up. Make sure to identify all components.

Sketch:

!

Congratulations, you have built a rudimentary **refracting telescope** similar to the one made by Galileo. The basic principle behind a telescope like this one is to use a lens to gather and concentrate the light into a focused image, then, using a magnifier to make the image bigger in order to see more detail.

History Lesson #3

Galileo finally could begin his research in astronomy, but he needed a patron to give him the status of a natural philosopher. He attempts to request that the Prince Cosimo Medici II be his patron, however, the prince is in need of a mathematician, not a natural philosopher. Galileo decides he needs to convince the prince. While observing Jupiter, Galileo discovers that the planet has four moons orbiting it. This was a huge discovery at the time because it was believed that everything orbited the Earth, however, there were celestial bodies that had a different planet at the center of their rotational axis. He names them the "Medici Stars" in his book "Sidereus Noncius." He also wrote about the rings of Venus and the rocky surface of the moon, which was assumed to be flawless because it was a creation of God. Cosimo is thrilled to be immortalized in the form of a star in the heavens and agrees to take Galileo on as both his natural philosopher and mathematician.

PART B: Isaac Newton

History Lesson #4

Sixty years after Galileo showed the world how to create more powerful refracting telescopes, other astronomers and mathematicians were building increasingly longer telescopes in order to see further into the distance. Lenses that were the best for seeing far needed longer focal lengths, which led to telescopes as long as 60 feet in length! There was a need for longer telescopes because a lens with a short focal length refracts the light going through it too much, causing the colors in the image to separate, a phenomena known as dispersion, and leading to a fuzzy image with color fringes around the image. However, these telescopes were very difficult to maneuver without access to any machine components, expensive and impractical to anyone who wanted to obtain one. There were also problems with the light gathering lenses needing to be larger in size to increase the brightness of the image, which required mounts that could not support the heavier lens. Lenses need to be supported around the rim rather than by the face of the lens to allow light to pass through, however, supports of this type were bulky and inconvenient.

Newton began to ponder over the idea of mirrors to counteract these problems. Mirrors can reduce the amount of dispersion when light hits it, and mirrors can be fully supported across their entire expanse, which allows them to be much larger than lenses, allowing reflecting telescopes to collect more light to detect dimmer objects in the universe. He developed a theory based on constant relationship between refraction and dispersion, regardless of the type of medium, with which he used to guide his attempts at a better, more useable telescope. Similar to Galileo polishing his own lenses, Newton polished his own mirrors out of metal alloys (glass mirrors were unavailable at the time) to make them as precise as possible. This set a precedent for other mathematicians to try to learn mechanical skills in order to achieve better results.

Part 5

- Pick up a 75mm diameter mirror and secure it in its holder.

- Is it concave or convex?

- Use the foam-and-sticks model to illustrate what happens to the light once it hits this type of mirror. Briefly state your findingds.

- Set up a third meter stick, parallel to the other two. Place a 75mm diameter mirror at the end farthest from the flashlight and directly facing the flashlight.

- Where would you expect the image of the star to be concentrated? In the front of the mirror or in the back of it?

- Place the screen directly in front of the mirror. Can you see the the image of the star? Explain.

- Move the screen a little off to the side so that at least some of the light is hitting the mirror. Make sure to bring the resulting image into focus.
- Now set up the magnifier lens in front of the screen to make the image bigger. Can you view the image through the eyepiece? Is it possible with the set up you have without changing the angle of the meter stick?
- If not, can you suggest a solution? Once you have come up with a potential solution, seek your instructor for further directions.
- Take a look at the 25 mm diameter mirror attached to a holder. What do you notice about its physical properties?
- Place the 25 mm diameter mirror on the meter stick and slide it into the place where the screen image was, making sure the height of the mirror matches the height of the image on the screen. Tilt the 75 mm diameter mirror's holder forward or backwards as needed to adjust the height of the image.
- What does this do to the image of the star? Can you see the image in the mirror? Explain.
- Pick up the magnifier lens and hold it between your eye and the star image. Try to line everything up in such a way that you can see the image of the star through the magnifier (the eyepiece). Remember to focus your image.
- Make a sketch of your set up. Make sure to identify all components.

Sketch:

! Congratulations, you have built a basic **reflecting** telescope similar to the one made by Newton. The basic principle behind a telescope like this one is to reflect the light off a mirror and concentrated it to make a bright image.

History Lesson #5

Alternatively, many mechanical workers of the time period were also trying to improve the quality of their products using mathematics. One such individual, John Dollond, in the first half of the 18th century, was a silk weaver who had an interest in optics. He was able to disprove Newton's theory on refracting and dispersion by showing that the type of medium affects refraction and dispersion independently. Based on this new theory, he was able to create a telescope using different types of glass that were achromatic, or did not disperse the color when light passed through them. This caused an interest in refracting telescopes to resurface in Europe. Over the past few centuries, both types of telescopes, refracting and reflecting, have seen significant changes, but the basic concepts remain the same. There have also been developments of new kinds of telescopes such as the Hubble telescope which orbits the Earth to minimize the distortion that our planet's atmosphere has on the image produced. Astronomers will continue to try to see farther and farther into space, but even amateur astronomers can help out the scientific community with a decent, small scale telescope in their own backyard thanks to work of hundreds of scientists, mathematicians, and engineers over the past few centuries.

INSTRUCTOR'S VERSION

Lab Activity: Early Telescopes

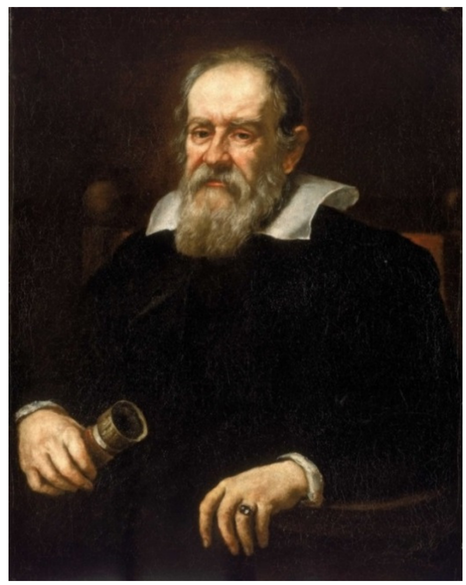
Adapted from the Outreach ToolKit Manual, Astronomical Society of the Pacific

Instructions

**These instructions are only meant to be a basic guide and *not* step-by-step directions. This lab is meant to recreate the experience of Galileo and Newton in designing and improving telescopes. Try to think of this activity from the perspective of early scientists who did not necessarily know every step of the way but rather had to apply theoretical knowledge and work experimentally in a trial-and-error fashion. **

PART A: Galileo Galilei

History Lesson #1



Portrait of Galileo Galilei, 1636.

Lenses were often used as reading glasses before the idea of combining them to create a stronger magnification. In 1608, Hans Lipperhey, a Dutch spectacle-maker in Middleburg, Holland applied for a patent for "a device to observe things at a distance." His application was denied on the grounds that, despite its usefulness, the design of the device was too simple to prevent others from discovering how to make it on their own accord. From the date recorded on the application, Hans Lipperhey is most often credited for inventing the telescope. However, many tradesmen were illiterate in the early 1600's and did not keep records, so it is difficult to determine if this was the true origin.

By the spring of 1609, small, weak telescopes could be found in the shops of spectacle-makers in northern Europe, and the invention quickly traveled south to Italy. In Venice, Fra Pauolo Sarpi, a friend of Galileo, heard about the device and told his colleague. At the time, Galileo was only a mathematician, a role receiving less respect than most in academia. He was a very smart and well-known mathematician but he aspired to be a natural philosopher, one of the most respected fields, because of it consisted of studying the divine creation of our world, in an era where the church played a major role in daily life. Galileo saw the chance to create a high-quality "spyglass" to present as an asset to both the Italian government, and by using it to study the heavens in more detail than anyone previously, in order to gain respect as a natural philosopher.

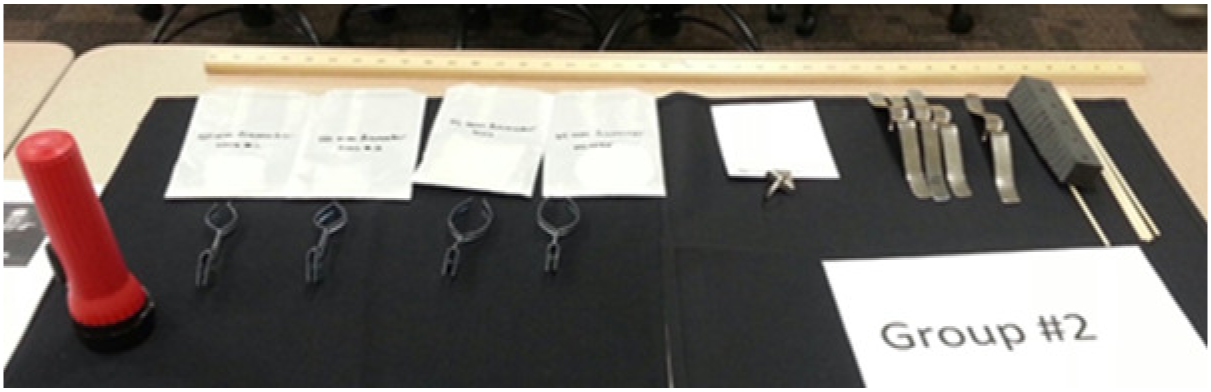


Figure 2: Original layout from left to right, flashlight with a star cut out, 4 lens holders, 3 lenses in a labeled envelope, 1 mirror in a labeled envelope, a screen with a holder,2 meter sticks, 4 meter sticks supports, foam and sticks.

Part 1

- Start out by looking at two smaller 50 mm diameter lenses over a piece of paper with a small font type.

- Do these both magnify the same?
- No

- What do you notice about their physical properties?
- One is thick (50mm FL) and the other one is thin (200mm FL), also curved outwards or convex.

- What connections can you make based on these findings?
- The thicker one (50mm FL) provides a stronger magnification.

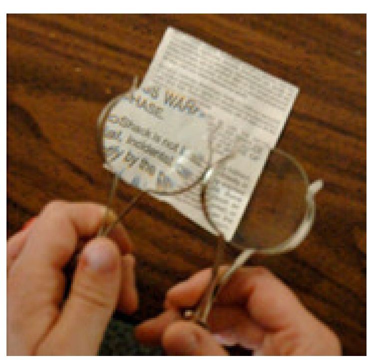


Figure 3: Hold the two 50mm (smaller) diameter lenses over the paper with small type.

!

Convex objects have an outward curving surface, whereas **concave** objects have an inward curving surface. The two lenses you have worked with are known as **double-convex** because they have two outward curving faces which makes them thicker in the middle and narrower at the edges.

Part 2

- Imagine having a clear flat piece of glass, like a window, between you and your partner. Would you be able to see him/her clearly? Next, carefully hold the stronger 50 mm diameter lens near your partner's face. How would this compare with the flat glass? Speculate how your findings can be explained in terms of physical properties and light interactions.
- Yes, would be able to see clearly with a flat glass. However, cannot see as clearly with the convex lens. This is because the light reflecting off your partner's face goes straight through the flat glass with little or no change in direction. Unlike the flat glass window, the lenses you are comparing are curved, so they change the direction of the light coming through them. In other words, lenses gather and concentrate light into a small area by changing the direction of the light.

- To better illustrate light behavior, you are going to use the foam-and-sticks model.

- In this activity, each stick will represent the direction of a light ray. Push 5 sticks through the foam strip (no more than 0.5 in sticking out on the back side) such that they are parallel to each other and evenly spaced out. This setup is a representation of how the light rays travel through a flat glass.

- Now, slightly curve the foam toward the skewers such that they come to an intersection in the middle. This setup is a representation of how the light rays travel through a convex lens.

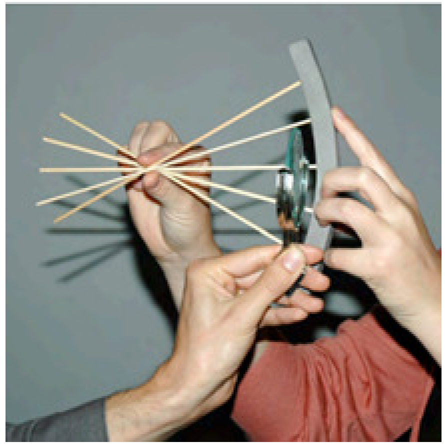


Figure 4: Use foam and sticks to illustrate light behavior.

!

The phenomenon you just observed is known as **refraction**. Refraction occurs when a light ray changes its direction because it entered a different medium (which is easier or more difficult to travel through) causing its speed to change. In the case of the flat glass, where the glass medium has a consistent width, the light ray travels at a uniform speed with little to no change in direction. However, in the case with the convex lens, where the glass medium is inconsistent (thicker in the middle and thinner at the edges), the light ray no longer travels at a uniform speed and as a result, changes its direction.

Part 3

- Now, compare the weaker of the two 50 mm diameter lenses with the 75 mm diameter lens.

- Do these have the same magnification powers?
- Yes, both are approximately the same.

- What effect does the diameter have on magnification?
- The diameter has no effect on the magnification.

- Is the 75 mm diameter lens concave or convex?
- It is also convex.

Figure 5: Hold the 50mm diameter 200mm FL lens (thinner) and the 75mm diameter lens over the paper.

- About 5-8 feet away from your work station, set up a flashlight. This flashlight creates an image of a star which is going to represent the heavens.

From now on, all classroom lights must be off.

- Set up and secure two meter-sticks parallel to each other and with the scale facing up. Using appropriate fixtures, place the two lenses on adjacent meter-sticks. Secure a screen in front of the lenses. Make sure that the light beam is pointing directly toward the lenses and not angled in any direction. You may need to elevate the flashlight in order to accomplish this.

- Can you see the two fuzzy images of the star on the screen? How can you bring both of them into focus?
- Yes, the stars appear fuzzy but can be focused by moving the lenses closer or farther away from the screen.

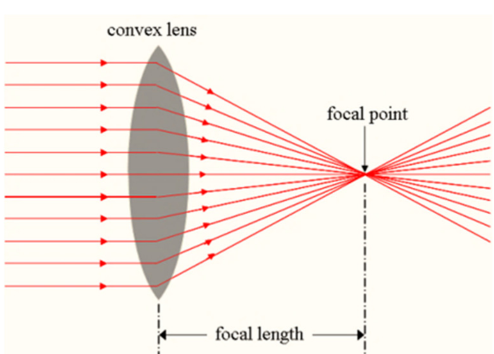
- After adjusting your setup to ensure that both images are in focus, measure the distance between each of the lenses and the screen.
- 50 mm diameter lens: ____________ 75 mm diameter lens: _____________

Figure 6: Flashlight set up 5-8 away from the work station including two adjacent meter sticks, two lenses and a screen.

The shortest distance at which a lens can focus is known as the **focal distance**. The sharp image of the star is created on the screen at the point at which all light rays passing through the lens converge. This point is known as the principal point of focus or simply, the **focal point**.

- Explain why the images go in and out of focus? Make a simple sketch of your setup, make sure to label all components (lens, light rays, screen, focal point, focal distance). Hint: Use the foam-and-sticks model if you are having difficulties visualizing this.
- The light coming through each lens is being bent and concentrated into a small area, creating an image. So there is only one point where the image is in focus, which is at the focal point where all the light rays come together.

Sketch:



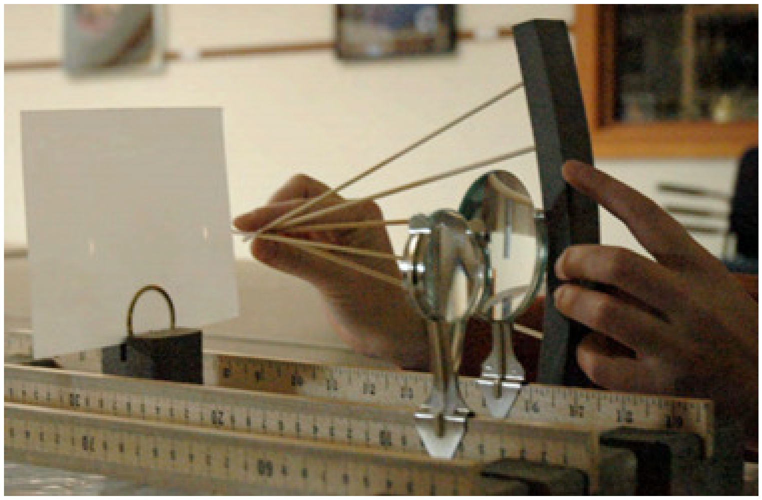


Figure 7: Bend foam and sticks to a point with the focal length the same as the focal length of the75 mm diameter lens.

- Do you notice anything odd about the images being projected? Explain using your sketch.
- Yes, they are actually upside down. Because of the refraction path, the ray that hits the lens at the top comes out at the bottom past the focal point, whereas the ray that hits the lens at the bottom comes out at the top past the focal point.

- Compare the two images of the star. Is there a difference in their brightness? Do you think both lenses gather the same amount of light?
- The larger lens (75mm) produces a brighter image. The two lenes do not gather light equally.

- Explain what accounts for these differences. Hint: Use the foam-and-sticks model to help you answer this question. Keep in mind that every stick represents a ray of light.
- In the case with the 75mm lens, it takes *all* the light hitting it (represented by 5 sticks), then curves it, concentrates it and produces a bright image. However, in this case with the 55mm lens, it collects less light (can be represented by 3 inner sticks), so when it curves and concentrates it, the resulting image is dimmer because not as much light is being gathered.

- Think about the pupils of your eyes. How much light do they gather compared to your two lenses?
- Even less than the lenses.

- What happens to your pupils when you go into a dark room after being outside in the daylight?
- It gets bigger.

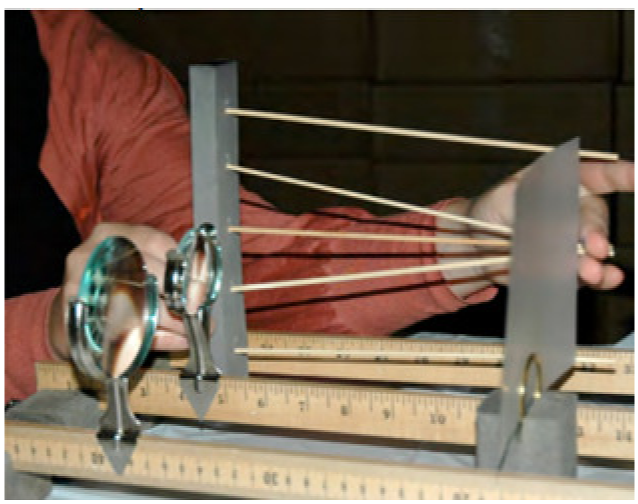


Figure 8: Take the 3 inner sticks and hold them together at the focal point of the 50 mm diameter lens to explain its weaker light gathering abilities.

! When entering a dark room after being outside, your eyes adjust in order to collect more of what- little light there is in the dark room. Telescopes gather light in a similar way – as the opening (the lens) gets larger, the dimmer objects become easier to see. The opening through which light travels (i.e. the diameter of the telescope's lens) is known as the **aperture**.

History Lesson #2

Galileo spent months guessing and testing different lenses, because he did not have access to any of the designs from the tradesmen, until he finally created an instrument he deemed worthy. In the summer of 1609, Galileo had built his first telescope with a 3x magnification. He hit a road block when all the lenses he could acquire from local spectacle-makers were poor quality, and not the strengths needed, so he taught himself how to grind lenses. This was a process that takes many hours of concentration in order to perform correctly as there was no other way than to do it by hand. His telescope solved many issues previous telescopes had such as low brightness and poor clarity of the image. By the fall, he had a telescope of 8x magnification, which earned him the position of the Padua Chair of Mathematics. In November, he had a telescope with a magnification of 20x which he used to conduct most of his research in astronomy, and was the most powerful telescope available for the time period.

**Following in Galileo's footsteps, you have successfully familiarized yourself with various lenses and their properties. Now, you are ready to put together a rudimentary telescope. **

Part 4

- Pick a lens which has the best light gathering abilities. This lens, called the "objective", should be used to concentrate light into the image of the star.

- Pick a lens which can produce the best magnification. This lens, called the "magnifier" or the "eyepiece", should be used to make the image of the star bigger so that it could be observed in greater details.

- Using these two lenses and previously acquired knowledge, set up a rudimentary telescope on a single meter stick.

- Look through your telescope. What do you see?
- The image is bigger and brighter.

- Make a sketch of your set up. Make sure to identify all components.

Sketch:

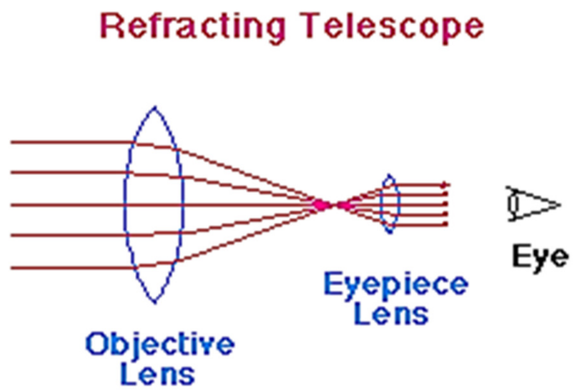


Figure 9: Place the magnifier on the meter-stick section on the opposite side of the screen of the larger lens. Lean down to look through the lens at the image on the screen. Now remove the screen and look through the magnifier, called the eyepiece, because it's what we look through with our eye.

!

Congratulations, you have built a rudimentary **refracting telescope** similar to the one made by Galileo. The basic principle behind a telescope like this one is to use a lens to gather and concentrate the light into a focused image, then, using a magnifier to make the image bigger in order to see more detail.

History Lesson #3

Galileo finally could begin his research in astronomy, but he needed a patron to give him the status of a natural philosopher. He attempts to request that the Prince Cosimo Medici II be his patron, however, the prince is in need of a mathematician, not a natural philosopher. Galileo decides he needs to convince the prince. While observing Jupiter, Galileo discovers that the planet has four moons orbiting it. This was a huge discovery at the time because it was believed that everything orbited the Earth, however, there were celestial bodies that had a different planet at *the center of their rotational axis. He names them the "Medici Stars" in his book "Sidereus Noncius." He also wrote about the rings of Venus and the rocky surface of the moon, which was assumed to be flawless because it was a creation of God. Cosimo is thrilled to be immortalized in the form of a star in the heavens and agrees to take Galileo on as both his natural philosopher and mathematician.*

PART B: Isaac Newton

History Lesson #4

Sixty years after Galileo showed the world how to create more powerful refracting telescopes, other astronomers and mathematicians were building increasingly longer telescopes in order to see further into the distance. Lenses that were the best for seeing far needed longer focal lengths, which led to telescopes as long as 60 feet in length! There was a need for longer telescopes because a lens with a short focal length refracts the light going through it too much, causing the colors in the image to separate, a phenomena known as dispersion, and leading to a fuzzy image with color fringes around the image. However, these telescopes were very difficult to maneuver without access to any machine components, expensive and impractical to anyone who wanted to obtain one. There were also problems with the light gathering lenses needing to be larger in size to increase the brightness of the image, which required mounts that could not support the heavier lens. Lenses need to be supported around the rim rather than by the face of the lens to allow light to pass through, however, supports of this type were bulky and inconvenient.

Newton began to ponder over the idea of mirrors to counteract these problems. Mirrors can reduce the amount of dispersion when light hits it, and mirrors can be fully supported across their entire expanse, which allows them to be much larger than lenses, allowing reflecting telescopes to collect more light to detect dimmer objects in the universe. He developed a theory based on constant relationship between refraction and dispersion, regardless of the type of medium, with which he used to guide his attempts at a better, more useable telescope. Similar to Galileo polishing his own lenses, Newton polished his own mirrors out of metal alloys (glass mirrors were unavailable at the time) to make them as precise as possible. This set a precedent for other mathematicians to try to learn mechanical skills in order to achieve better results.

Part 5

- Pick up a 75 mm diameter mirror and secure it in its holder.

- Is it concave or convex?
- Concave.

- Use the foam-and-sticks model to illustrate what happens to the light once it hits this type of mirror. Briefly state your findingds.
- The light hitting the mirror is bent and concentrated to a point.

- Set up a third meter stick, parallel to the other two. Place a 75mm diameter mirror at the end farthest from the flashlight and directly facing the flashlight.

- Where would you expect the image of the star to be concentrated? In the front of the mirror or in the back of it?
- In the front.

- Place the screen directly in front of the mirror. Can you see the the image of the star? Explain.
- No, the light source is covered.

Figure 10: Move the screen to the side so that at least some of the light is hitting the mirror and an image form.

- Move the screen a little off to the side so that at least some of the light is hitting the mirror. Make sure to bring the resulting image into focus.

- Now set up the magnifier lens in front of the screen to make the image bigger. Can you view the image through the eyepiece? Is it possible with the set up you have without changing the angle of the meter stick?
- No, because your head blocks off all light.

- If not, can you suggest a solution? Once you have come up with a potential solution, seek your instructor for further directions.
- Need a mirror that is angled.

- Take a look at the 25 mm diameter mirror attached to a holder. What do you notice about its physical properties?
- It is flat unlike all others.

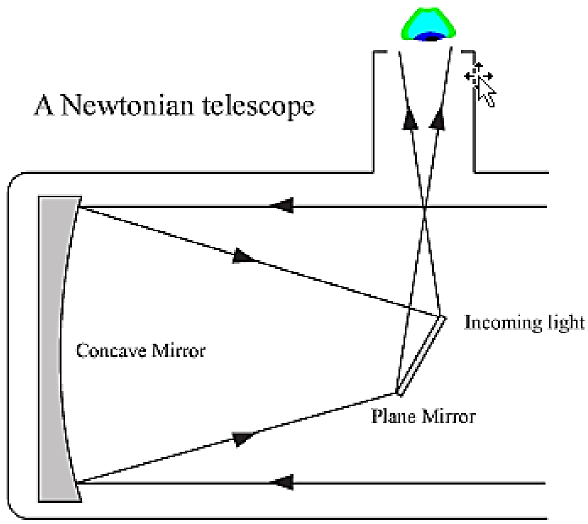
- Place the 25 mm diameter mirror on the meter stick and slide it into the place where the screen image was, making sure the height of the mirror matches the height of the image on the screen. Tilt the 75 mm diameter mirror's holder forward or backwards as needed to adjust the height of the image.

- What does this do to the image of the star? Can you see the image in the mirror? Explain.
- It reflects the image off to the side. Yes, a flat mirror reflects the image back at the same angle.

- Pick up the magnifier lens and hold it between your eye and the star image. Try to line everything up in such a way that you can see the image of the star through the magnifier (the eyepiece). Remember to focus your image.

- Make a sketch of your set up. Make sure to identify all components.

Sketch:



! Congratulations, you have built a basic **reflecting** telescope similar to the one made by Newton. The basic principle behind a telescope like this one is to reflect the light off a mirror and concentrated it to make a bright image.

History Lesson #5

Alternatively, many mechanical workers of the time period were also trying to improve the quality of their products using mathematics. One such individual, John Dollond, in the first half of the 18th century, was a silk weaver who had an interest in optics. He was able to disprove Newton's theory on refracting and dispersion by showing that the type of medium affects refraction and dispersion independently. Based on this new theory, he was able to create a telescope using different types of glass that were achromatic, or did not disperse the color when light passed through them. This caused an interest in refracting telescopes to resurface in Europe. Over the past few centuries, both types of telescopes, refracting and reflecting, have seen significant changes, but the basic concepts remain the same. There have also been developments of new kinds of telescopes such as the Hubble telescope which orbits the Earth to minimize the distortion that our planet's atmosphere has on the image produced. Astronomers will continue to try to see farther and farther into space, but even amateur astronomers can help out the scientific community with a decent, small scale telescope in their own backyard thanks to work of hundreds of scientists, mathematicians, and engineers over the past few centuries.

List of Required Materials:

Count per group	Count total	Item	Description	Item #	Source	Price total
1 piece	1 pack	Glass mirror	1" flat and round	1613-55	http://www.consumercrafts.com/	$ 1.37
1	6	Lens: double convex	50mm diam x 200mm FL	26361	http://www.scienceenthusiast.com/	$ 23.70
1	6	Lens: double convex	50mm diam x 50mm FL	26355		$ 29.70
1	6	Lens: double convex	75mm diam x 200mm FL	26371		$ 41.70
2	10	Lens holders	(a.k.a. lens support) - 38mm lens (for 50mm lenses)	25089		$ 12.90
2	10	Lens holders	(a.k.a. lens support) - 75mm lens (for 75mm lens)	25090		$ 19.90
2 packs	10 packs	Meter sticks supports	Comes as a pack of 2	25095		$ 29.50
1	5	Screen support	(a.k.a. screen holder)	25093		$ 8.45
1 piece	1 pack	Screen with scale	Comes as a pack of 5	25094		$ 7.45
1	6	Marker and object	Comes as an assembly	25091		$ 10.14
5	25	Skewer sticks	8" or similar size		Grocery store	$ 4.20
	1 roll	Aluminum foil	2"x2" square sheets or similar size			$ 4.97
	1 roll	Wax paper	2"x2" square sheets or similar size			$ 4.79
1	5	Foam strip	1-1/4" x 8" (needs to be able to bend but not too flimsy)		http://www.amazon.com/	$ 7.79
5	25	Envelopes	Wax paper bags for storing/labeling lenses			$ 8.98
	1	Super glue			Home Depot	$ 3.48
	1 roll	Electrical tape				$ 3.98
2	10	Meter sticks (or half-meter)				$ 44.70
1	5	Incadesent flashlight	Comes with batteries			$ 14.90
					Total:	**$ 282.60**

List of Additional Materials:

- Scissors
- Utility knife
- Paper template

De-identification Code ____ ____ ____ ____ ____
Date:

Post-Lab Assignment

1. Did your Galilean Telescope work?
   a. Please explain why you set up your telescope the way you did by referring to your sketch.

   b. What problems did you experience and how did you address them?

2. Explain, using your sketch, what was happening to the image at each step within the refracting telescope design. Use appropriate names for all components.

3. Galileo further improved his telescope by flipping the image to be the right side up. Propose a solution to how you could modify your telescope to fix this problem. (Hint: think of various lens types available.)

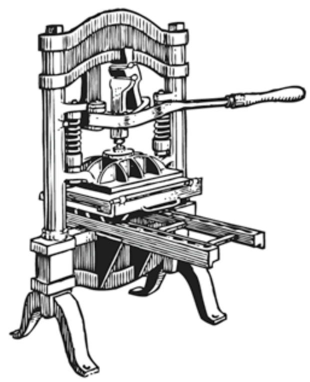
4. Did your Newtonian Telescope work?
   a. Please explain why you set up your telescope the way you did by referring to your sketch.

   b. What problems did you experience and how did you address them?

5. Explain, using your sketch, what was happening to the image at each step within the reflecting telescope design. Use appropriate names for all components.

Group’s members:
Date:

Printing Press Workshop



The Historical Importance of the Printing Press and
It’s Value to the Scientific Community

Each small group will be assigned a topic relating to the development and use of the printing press. You will choose your topic from the list below. Only one group is allowed per topic, so if another group has already selected a topic then you may not take theirs. Your task is to create a short presentation (4-6 minutes) in the format of your choice to introduce this topic to the rest of the class. The format of the presentation must be a tangible product in the form of a computer file, for example, if you decide to do a skit, then you should videotape it and submit it, or if you do a PowerPoint then the presentation must be submitted. The files for your presentations will be due **at midnight on Thursday, March 27th**, in the discussion section of MyWPI. You should use at least two reliable sources and cite them properly. You will be presenting your topic using the file you submitted to the class on **Friday, March 28th.** After the presentations, you will discuss some questions provided by the instructor based on information in the presentations, and conclusions you can draw from them.

Topics:

- Group #1: Education systems before mass produced books
- Group #2: Literacy before and after
- Group #3: Effect printing of the bible had on religion
- Group #4: Effect the printing press had on the arts
- Group #5: The printing businesses - publishing
- Group #6: Economy change due to printing

Presenting:

- For guidance on how to present, the WPI library suggests this short video by Don McMillan: http://tinyurl.com/LifeAfterDeathPowerPoint
- For more help with public presentations, watch a 20 min video on the Truth About Public Speaking by James O’Rourke: http://tinyurl.com/TruthAboutPublicSpeaking

Group's members:
Date:

Discussion – Printing Press workshop presentations

A different member of your group will be this week's write-up author. Reacquaint everyone with your name and make sure that person writes down every member's complete name at the top of a page for note taking. In your discussion, try to cover all four of the tasks outlined below.

1. We all heard group presentations about the impact of the printing press on European science and culture.

    - Of the presentations that <u>other</u> groups made, what are the most important points that members of your group learned about? Why are these points important?

    - Were there historical claims made by any other group that you would question, requiring a better presentation of evidence before you accepted them as valid? Provide specific examples of these claim(s), and of the critical thinking questions that you would offer to probe/challenge each assertion.

    - Taken altogether (based on your group's research and what you heard from other groups), what conclusions can you draw about the impact of the printing press on the history of science? How did the printing press directly help to change the face of science? What effects did the contemporary culture have on scientific advancement?

11 APPENDIX C: IMPLEMENTED ASTRONOMY UNIT

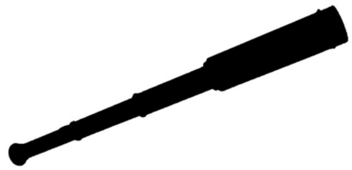
The following document highlights modifications and additional documents that were included in the implemented version of the Astronomy Unit.

Table of Contents:

- [Added] First Day Preliminary Survey
- [Modifications] Lecture Presentations
- [No Change] Pre-Lab Assignment
- [No Change] Lab Activity: Early Telescopes
- [No Change] Lab Activity: Early Telescopes (Instructor's Version)
- [No Change] Post-Lab Assignment
- [Added] Post-Lab Survey
- [No Change] Printing Press Workshop
- [Modifications] Discussion – Printing Press workshop presentations; Galileo, Sidereus Nuncius; Mlodinow, Euclid's Window
- [Added] Midterm Qualtrics Survey
- [Added] Midterm Questions

De-identification Code ____ ____ ____ ____ ____
Date:

First Day Preliminary Survey



1. What do you think the process of scientific discovery entails?

2. What physics classes have you taken? Did any of them cover optics to any extent?

Lecture Presentations

All of lecture materials were prepared and presented by Professor David Spanagel. None of the proposed lecture materials were utilized.

Pre-Lab Assignment

The proposed pre-lab assignment was used without any modifications.

Lab Activity: Early Telescopes

The proposed lab activity on early telescopes was used without any modifications.

Lab Activity: Early Telescopes (Instructor's Version)

The proposed instructor's version of the lab activity on early telescopes was used without any modifications.

Post-Lab Assignment

The proposed post-lab assignment was used without any modifications.

De-identification Code ____ ____ ____ ____ ____
Date:

Post-Lab Survey

1. How was this lab similar or different to other college-level lab courses you have taken?

2. Was there enough time to complete the lab?

3. Describe the quality of the instructions for the lab by choosing one of the following:

Guided me along step-by-step	◦	◦	◦	◦	◦	◦	◦	Left me stumbling in the dark

Printing Press Workshop

The proposed printing press workshop was used without any modifications to the written instructions.

Discussion – Printing Press workshop presentations; Galileo, *Sidereus Nuncius*; Mlodinow, *Euclid's Window*

The following questions were added by Professor David Spanagel to the proposed discussion.

1. In the introductory and concluding essays that envelope our edition of *Sidereus Nuncius*, editor Albert Van Helden describes the circumstances of how and why Galileo transformed the novelty (spyglass) into the scientific instrument (telescope), and he explores the reception of Galileo's discoveries in terms of the reproducibility of sufficiently powerful replicas.

    - What were the first purposes people thought of as being useful or desirable applications of the spyglass? How was Galileo similar or different in his initial use of the new tool?

    - Did Galileo have unprecedented ideas about how to apply the spyglass to astronomy?

    - What kinds of evidence and/or expertise distinguished Galileo's astronomical findings from those of any of his predecessors? What did he see that no one expected to see?

2. At the beginning of the 17th century, a revolution in cosmology (from geocentrism to heliocentrism) was already well underway. Despite the fuel Galileo's telescope would add to debates begun by Giordano Bruno, Nicolas Copernicus, and Johannes Kepler, Copernican ideas would not achieve a broad consensus for many more decades. Discuss what Van Helden means by "methodological and epistemological problems" faced by Galileo's mathematical and observational bids to overturn long established philosophical "truths."[1]

    - How do you think Galileo chose which celestial phenomena to focus on and report about? Was he intentionally hunting for evidence to support Copernicus from the start, or was he just randomly finding surprises and describing them? Cite specific examples from the text to support your responses to this question.

    - Why did Galileo's instrument-aided reports of celestial phenomena make him the focus of such intense philosophical controversy? What was particularly objectionable about Galileo's astronomical findings, in terms of prevailing

[1] Albert Van Helden, in Galileo Galilei, *Sidereus Nuncius* (Chicago: U. Chicago Press, 1989): 88.

Aristotelian natural philosophy <u>and</u> in terms of prevailing religious orthodoxy (the Catholic Church's doctrines)?

- In addition to *methodology* (how we obtain correct data) and *epistemology* (how we make sense of what we observe), Copernicanism challenged the prevailing *ontology* (what do we think is real). Why should anyone accept the claim that the earth "moves"? Why do you suppose that the telescope was able ultimately to undermine a predominant theory which conformed so clearly to experience (e.g. we see "the sun rise" every day)?

3. Try to pull the various loose pieces of today's discussion together.

- How might Galileo's embrace of Copernicanism and his devotion to astronomy be seen as part of a larger strategy to use mathematics to demolish the intellectual hegemony Aristotelian natural philosophy had exercised for almost exactly 2000 years?

- How do the achievements of Nicole Oresme and Rene Descartes (as discussed in *Euclid's Window*) either reinforce or undermine this larger claim about relationship between innovative mathematical thinking and the staying power of medieval natural philosophy?

- What essential roles did European rulers play in enabling important scientific developments between the 9^{th} and 17^{th} centuries? Discuss the examples of King Charlemagne, the Medici family, and Queen Christina.

Midterm Qualtrics Survey

ID Number

What is your assigned de-identification code for this course (HI 2352)?

Telescope Lab

Please rate the telescope lab that you performed on the following qualities (1 = Not Very, 7 = Very):

	1	2	3	4	5	6	7	N/A
Interesting	○	○	○	○	○	○	○	○
Memorable	○	○	○	○	○	○	○	○
Difficult	○	○	○	○	○	○	○	○
Appropriate Use of Class TIme	○	○	○	○	○	○	○	○
Relatable to Lecture Material	○	○	○	○	○	○	○	○

How well did the lectures and assigned readings help prepare you for the lab (1 = Not Very, 7 = Very)?

1	2	3	4	5	6	7	N/A
○	○	○	○	○	○	○	○

Do you feel as though this lab adequately portrayed the historical context in which Galileo and Newton worked on their telescopes? (1 = Not Adequate, 7 = Very Adequate)?

1	2	3	4	5	6	7	N/A
○	○	○	○	○	○	○	○

What is one theme you learned from the lab (aside from how to build a telescope)?

What is one thing you found interesting from the lab?

Would this lab run better if it was located in a laboratory classroom or a lecture space, for reasons such as putting yourself in the mind of the inventor, the instructor's ability to communicate directions, or access to needed materials?

- ○ A classroom would be better
- ○ The room choice would not affect the lab
- ○ A lab space would be better

Printing Press Discussion

Please rate the Printing Press Discussion that you participated in on the following qualities (1 = Not Very, 7 = Very):

	1	2	3	4	5	6	7	N/A
Interesting	○	○	○	○	○	○	○	○
Memorable	○	○	○	○	○	○	○	○
Difficult	○	○	○	○	○	○	○	○
Appropriate Use of Class Time	○	○	○	○	○	○	○	○
Relatable to Lecture Material	○	○	○	○	○	○	○	○

How well did the lectures and assigned readings help prepare you for your the small group presentations of the printing press (1 = Not Very, 7 = Very)?

1	2	3	4	5	6	7	N/A
○	○	○	○	○	○	○	○

Did you find it educationally beneficial to learn about the culture of the time period through your participation in small groups (1 = Not Very, 7 = Very)?

1	2	3	4	5	6	7	N/A
○	○	○	○	○	○	○	○

Did the presentations and discussion on the printing press work well with the rest of the discussion topics?

1	2	3	4	5	6	7	N/A
○	○	○	○	○	○	○	○

Overall Course

For the topic of astromony, did you feel the balance of lectures, reading assignments, discussions, and lab to be appropriate?

- ○ Yes, a good balance
- ○ No, please explain why below:

Do you think labs like the one you participated in would be a valuable addition to other history courses at WPI?

What does the process of scientific discovery entail? What affects scientific progress?

Are there any other comments or thoughts you have for our IQP group?

De-identification Code ____ ____ ____ ____ ____
Date:

Midterm Exam

Part I. Identifying and contextualizing. (Each question is worth one point.) Choose to identify four of the following six items listed in this part. For each instrument or conceptual tool that you choose, write a short paragraph (of two or three complete sentences) in your exam booklet, which addresses all of the following: Who is primarily associated with its discovery/invention? Roughly when (in which century) and where (what country or region) was it first used to advance work in the exact sciences? What important consequences do historians of science attribute to this technology/technique, and why?

- Irrational numbers
- Latitude and longitude lines
- Printing press
- Reflecting telescope
- Refracting telescope
- XYZ coordinate system

Part II. Write an essay comparing and contrasting Galileo's and Herschell's backgrounds, struggles, and achievements.

12 APPENDIX D: OUTLINE OF PROPOSED ANATOMY UNIT

The following document is an outline of the Anatomy Unit.

Suggested readings

- Blood and Guts: shows the culture surrounding vivisection and dissection
- Discussion articles (see conference section)

Lecture outline

- Basic introductory lecture on electricity and voltage
- Luigi Galvani (Italy 18th Century)
  - Teaches anatomy at University of Bologna (1762)
  - By 1780s focusing on animal electricity
  - Flawed theories of animal electricity led to Volta's research
  - Animal electricity
  - electric fluid
  - Galvanism
  - Galvanometer
- In class demonstration with frog legs
  - Luis Galvani in the late 18th century
  - Accidental discharge of static electricity to an exposed nerve caused muscle twitch
  - When use on the day of action potential lecture shows the connection that lead early anatomists to suspect a connection between movement and electricity (bioelectricity, galvanism, electrophysiology)
- Alessandro Volta (Italy 18th century)
  - Voltaic pile 1799 (battery)
  - Volt = unit of electromotive force
  - Proves that animal tissue conducts electricity but is not a source
  - First battery: two electrodes; copper and zine, electrolyte of sulfuric acid or brine saltwater
- Galen Born 131 CE
  - Physician for gladiators and Marcus Aurelius
  - Researched kidneys and spinal cord in controlled experiments
  - Dissected apes to determine earliest set of data on human anatomy
  - Determines that observation is crucial
- Mondino de Luzzi:
  - Public dissections late 13th early 14th century in Italy
  - Tripartite theory:
    - Skull: superior ventricle
      - Animal members
    - Thorax: middle ventricle
      - Spiritual members: heart and lungs
    - Abdomen: lower ventricle
      - Natural members: liver

    - First modern dissection manual: 1316 *Anathomia corporis humani*
- Andreas Vesalius
    - *De humani corporis fabrica*
    - Founder of modern human anatomy
    - Chair of surgery and anatomy at Padua
        - Used dissection as a primary teaching tool
        - He carried out the dissections but encouraged students to participate
        - Hands-on observation is most effective
    - 1538: *Tabulae anatomicae sex*
        - Wooden anatomical posters
    - 1539: *Institutiones anatomicae*
        - Anatomical handbook
    - Disproves Galen (previous authority)
- Action potential and the Sarcolemma
    - Resting sarcolemma is polarized
        - Potential difference across membrane
        - Negative inside relative to outside
    - Generation of an end plate potential
        - Ach binding to receptors on the NMJ
    - Depolarization
        - Threshold is reached an action potential is progranda
    - Repolarization
        - Restoration of initial conditions
- AC molecules bind to receptors at the NMJ
- Ligand gated ion channels open
    - Allows sodium and potassium ions to pass
    - Sodium in
    - Potassium out
    - More sodium moves than potassium
- Results in a change of relative charge
    - Interior becomes less negative
    - Depolarization
- The initial depolarization is called end plate potential
- The end plate potential spreads to nearby membrane
    - Opens voltage gated sodium channels
    - Allows more sodium to enter following electrochemical gradient
- Once threshold reached action potential is generated
- The action potential travels down the sarcolemma
    - Spreads a wave of local depolarization
    - The local depolarization opens further voltage gated ion channels
    - This results in increased diffusion of sodium
- Voltage gated sodium ion channels close
- Voltage gated potassium channels open
    - Potassium rapidly diffuses inwards
    - Restores the negatively charged initial conditions
- Refractory period:

    - During repolarization the cell will not be able to be stimulated again until the resting potential is restored
- Cover Excitation Contraction Coupling if a lab on muscles is going to be conducted

Conference

- Discussion article:
    - Locate a primary source by Galvani on electricity
    - Alternative primary source by Volta who disagreed with Galvani
    - Animal Electricity and the birth of electrophysiology: the legacy of Luigi Galvani by Piccolino http://www.ncbi.nlm.nih.gov/pubmed/9739001
- The article at this link is a historical look at animal dissection: http://thechirurgeonsapprentice.com/2011/08/29/dissecting-the-living-vivisection-in-early-modern-england/#f1

Labs and demonstrations

We are hesitant to suggest a dissection because it may be off-putting to some students

- Laboratory:
    - Dissection: Chicken Leg to show muscle structure
    - Procedures can be found online that can be modified
- Alternative exercise:
    - Creating a system with strings and pulleys to move a model arm showing the movement caused by flexing of the bicep and triceps. (antagonistic muscle systems)
    - Pulling string past pivot point to bend arm
    - Discuss that energy comes from ATP and signal comes from AP and EC coupling