



Redesign of Microbiology Laboratory

Project Center: On-campus

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Abstract

In the 2017-2018 school year, a new experimental introductory biology laboratory will be added to courses offered at WPI. This experimental class will be a combination of the BB2901 and BB2905 course curriculums. Throughout this project, I examined recent research geared towards new and effective approaches to laboratory science education, student surveys, and the objectives and schedules for both BB2901 and 2905 as they stand today. In doing so, I have recommended a one-term, 1/3 credit course curriculum that combines the current classes, while still meeting all pertinent objectives.

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Literature Review

One of the primary objectives of this project is to develop a comprehensive assessment of new, and effective approaches to science education, specifically in a laboratory setting. The literature review summarizes key findings of several studies completed by research groups across the country. This information will be integral when assessing the approaches to education taken in the WPI courses, BB2901 and BB2905, and when providing any recommendations for the laboratory redesign.

How Students think about Experimental Design

A study released in 2013 in the journal *BioScience* set out to identify activities that would lead to higher learning gains in introductory biology lecture courses (Brownell, 2013). Explicit instruction and practice in experimental design is often lacking in these courses. This is because of perceived time pressures, large class sizes, and need to emphasize content as opposed to skills. The group examined two in-class group activities designed to test alternative hypotheses about how best to teach experimental design in a large biology lecture. The researchers reasoned that student understanding of experimental design could be improved by (1) working in a group to develop a hypothesis and design an experiment to test said hypothesis, and (2) work in a group to analyze and draw conclusions from mock experimental data. The first activity requires synthesis-level skills, while the second, relies heavily on analysis and evaluation skills. It was found in their research that both in-class activities, while different in their structure, were beneficial for improving students' experimental design ability. The data collected suggests that there may not be one right way to teach a skill as a complex as experimental design (Brownell, 2013).

The study concludes that explanations for success of design activities as opposed to normal lecture may be a closer alignment of design task with the application of these skills in

laboratory or examination. A student's ability to apply concepts to a new situation may also increase after completing a synthesis-level activity (Brownell, 2013).

Teaching Science Process Skills

In 2006, a study was completed by the Biology Fellows Program (BFP) at the University of Washington. Their results were subsequently released in the *Cell Biology Education* journal (Dirks, 2006). This program aims to enhance diversity in science by helping students succeed in the work-intensive introductory biology classes, and motivating them to engage in undergraduate research. This article provides insight for designing programs that aim to enhance the performance of beginning students of biology who want to obtain a life science degree.

Analysis of the performance of the students participating in the program shows that the students who lack certain science process skills are at risk for failing introductory biology. The BFP recruits freshmen who indicate to the UW admissions office that they intend to major in one of the following fields: Biochemistry, Bioengineering, Biology, Microbiology, Neurobiology, Zoology, and pre-health sciences.

The BFP is a two-quarter program at the University of Washington that starts in the winter quarter and meets once a week for 1.5 hours. In the BFP, science process skills are taught including: experimental design, data analysis, scientific writing, and science communication. These skills are taught using a “scaffolding” approach that progressively challenges students to master these skills, while it also weaves them together through individual homework assignments and small group work in class.

Students receive short lectures providing biological content and are given small group activities that allow them to collaboratively solve problems. Students are first taught basic

experimental design, how graphs and tables are used to present data, and the different components of a primary journal article. This knowledge is reinforced with repeated assignments that require students to apply this information to new situations. Later, students are given more advanced assignments where they must synthesize these skills by using scientific information and related data to present results, draw conclusions, and make predictions.

The students were tested as to whether they gained proficiency in the areas of interpreting graphs, experimental design, and data analysis over the course of the program. Several tests were administered to the students in a pre- and post-test manner. The post-test was administered after the BFP course was completed.

The programs found that, on average, students performed better on experimental design and graphing post-tests than on pre-tests. Students who scored below the median on the pretests showed statistically significant increases on the 36-question multiple choice, experimental design, and graphing post-tests. The average gains were 10% on the multiple choice test, 65% on the experimental design portion, and 20% on the graphing test, respectively. Thus, the BFP imparts basic experimental design and graphing skills to those students who lack these skills coming into the program. It also concludes that both traditional lecture styles and unique in-class activities help improve students' skills in STEM majors (Dirks, 2006).

Strategies for Engagement and Critical Reasoning

This study, completed and submitted to the Integrative and Comparative Biology Journal, established three pedagogical strategies that together can make a large difference in students' understanding and acceptance of evolution. They include: extensive use of interactive engagement, a focus on critical thinking in science (especially on comparisons and explicit criteria), and using both of these in helping the students actively compare their initial

conceptions (sometimes religious) with widely accepted scientific fact on the process of evolution (Nelson, 2008).

Nelson's research referenced Hake, a researcher in physics education (Hake, 1992). Hake defined "traditional" teaching of physics as "relying primarily on passive-student lectures, recipe labs, and algorithmic problem exams" and "interactive engagement" methods as "those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors."

Based on Hake's definitions, as well as Nelson's research, four key components for effective interactive engagement were identified:

1. Extensive structuring of learning tasks by the teacher
2. Strongly interactive student-student execution of the tasks
3. Effective debriefing or other assessments that provide prompt feedback to the teacher as to the extent that the intended learning succeeded
4. Instructional modifications by the teacher that take account of this feedback (Nelson, 2008).

New Perspectives on Teaching Practices and Perceptions

At the University of Maine, middle school and high school STEM teachers observed 51 different STEM courses across 13 different departments. They then collected information on the active-engagement nature of instruction.

The results show that faculty members may not be simply classified into two groups: traditional lectures or highly-interactive teaching. Instead, teachers tend to fall somewhere on a

broader spectrum, applying both techniques to their STEM classes at varying levels. Observation data also revealed that students' behavior differs greatly in classes with varied levels of lecture. Students who participate in courses with carrying levels of structure tend to be more engaged, and this is evident in their body language. Students with no variation tend to slouch more, pull out their cell phones, or fall asleep more frequently in classes with little-to-no variation. Although faculty members who teach large classes are more likely to lecture, there are also instructors of several large courses using interactive teaching methods, which seemed to benefit students. This benefit was reflected in their grades, as well as in course evaluations completed by the students (Smith, 2014).

Taking a Scientific Approach to Science Education

The objective of the research conducted by Wieman and his colleagues, and released in two issues of *Microbe Magazine*, is to describe the nature of expertise and how it is learned, as well as determine the best learning approaches (conventional vs. active) (Wieman, 2015).

This information is primarily based on the findings of cognitive psychology. It was concluded that in order to acquire expertise, one must develop a large amount of specialized knowledge, a specific framework for that knowledge, and a capacity to monitor his or her thinking about that field. It was also concluded that many active learning approaches achieve greater learning than conventional lecture, primarily based on findings of cognitive psychology.

Deliberate practice is a common process required for developing expertise. Deliberate practice requires many hours of intense practice and must include very specific characteristics as well as be challenging for learners. This form of practice requires full focus and effort to achieve

the objectives, but is still attainable for students. The tasks must practice the specific components of the expertise to be learned, and there must be timely and specific feedback.

Preliminary research on expertise, the mastery of skills, also indicates that it is better to delay the use of jargon in classes until after students are introduced to the relevant concepts. Memory has two components; long-term and short-term working memory. Working memory has extremely limited capacity, and only around five to seven new items can be retained for the typical person. Many studies show that anything that increases demands on the working memory unnecessarily during a learning activity reduces learning. Jargon is acceptable, however, it should be introduced only after students are introduced to new concepts and have some mastery.

In the second feature of this two-part series released by Wieman and his colleagues, they address why these improved teaching methods are not the norm in college and university science classes, and what it will take to achieve wide-spread adoption.

In order to achieve this goal, the study compared failure rates and performance on identical or nearly identical exams for courses that were taught using traditional lectures versus those that incorporated active learning methods. The conventional learning experiment involved only lecture time, whereas the active learning experiment conducted involved short, targeted readings prior to class, and subsequently, students were given a quiz or prelab on said reading. During class, students had questions to answer, and recorded them via clicker or worksheet. This involved students in individual work and discussions with neighbors. While there was considerable instructor talking, it was conducted as a follow-up discussion, and not as an initial lecture. On average in active learning courses, the failure rates are 35% lower, the exam scores are 0.47 standard deviations higher, and scores on concept inventory tests are 0.9 standard deviations higher. The researches also concluded that it is essential to make these changes on a

department level, since departments determine what and how topics in their discipline are taught (Wieman, 2015).

These research articles and sources are integral in the redesign of this laboratory. They provide insightful information moving forward, and are key points and information from each is used in the Results and Findings section to address the first objective of the project, which is to develop a comprehensive assessment of new, and effective approaches to science education, specifically in a laboratory setting.

1. Introduction

In 2012, the President’s Council of Advisors on Science and Technology called for a 33% increase in the number of science, technology, engineering, and mathematics (STEM) bachelor’s degrees completed per year in the United States. It is believed that this gain of STEM professionals will usher in gain of social, economic, and national security benefits as well (PCAST, 2012).

In 2012, fewer than 40% of students who entered college intending to major in a STEM field completed college with a STEM degree. Reasons students gave for leaving STEM include: uninspiring introductory courses, difficulty with the required math, and an academic culture that is sometimes not welcoming or attuned to members of groups underrepresented in the fields (specifically women and minorities). Based on their research, three recommendations were made in PCAST’s report: improve the first two years of STEM education in college, provide all students with the tools to excel, and diversify pathways to STEM degrees. Too often, even the “active learning” elements of today’s teaching regimens (laboratory courses) simply repeat classical experiments rather than engaging students in compelling experiments with the possibility and excitement of true discovery. Research findings have reported that college sophomores who engaged in research projects with a professor were significantly less likely to leave STEM majors than those who did not (PCAST, 2012).

Therefore, in order to achieve the goals set forth by “Engage to Excel,” it is recommended that STEM programs adopt new and innovative teaching practices to achieve the council’s goals.

For more than forty years, project-based learning has been at the heart of academics at WPI, termed the WPI plan. Project-based learning is defined as learning through projects that apply acquired skills and abilities to solve real-world problems. Major components of the plan in place

involve the Interactive Qualifying Project (IQP), as well as a Major Qualifying Project (MQP). The IQP is part of the WPI Plan, and is a project-based curriculum that give students the opportunity to work in interdisciplinary teams to solve problems or needs in science and society (“Interactive Qualifying Project”). At WPI the MQP is a professional design or research project completed collaboratively, and is considered the culmination of WPI’s project-based undergraduate education. The objective is to demonstrate knowledge specific to each student’s major, and solve a real-life issue (“Major Qualifying Project”). While these are the two projects most often associated with WPI, students typically complete one, or multiple projects within their classes throughout their four years of undergraduate studies. This project work can also be observed in laboratory settings. Students in most laboratories at WPI work in groups in order to achieve laboratory goals, and are encouraged to facilitate one anothers’ learning (“2016-2017 Undergraduate Catalogue”).

In the Biology and Biotechnology Department, this holds true. The primary focus of the Biology and Biotechnology Department at WPI is to make scientific and technological advances that also address the needs of society. It is the department’s objective to prepare well-educated students to be able to approach problems with creativity and flexibility. One of the key focuses in this preparation is active participation in the scientific process (“2016-2017 Undergraduate Catalogue”).

The main focus of this report is the BB2900 laboratory series within the Biology and Biotechnology curriculum at WPI. These laboratory courses provide foundational skills needed for the study of living organisms and systems at the molecular, organismal, and environmental level. In these labs students work in small groups to begin building the skills they need to carry into more advanced labs, their MQPs and professional careers. In particular, students gain

experience with scientific procedures and techniques, technical equipment, teamwork, laboratory safety, hypothesis generation and testing, scientific data analysis (including statistics), as well as oral and written scientific communication and skills. These experiences prepare them for their future at WPI, as well as their future post-graduation (“2016-2017 Undergraduate Catalogue”).

The goal of this report is to develop a laboratory course curriculum, combining two current courses, BB2901 and BB2905.

To accomplish this goal, the specific objectives are to:

1. **Develop** a comprehensive assessment of new, and effective approaches to science education, specifically in a laboratory setting.
2. **Characterize** the key objectives of each individual laboratory course, and combine the curriculum in a way such that all objectives are still met, and work cohesively in one course.
3. **Analyze** the data obtained from student surveys.
4. **Recommend** a course curriculum based on the information obtained in the above objectives.

2. Background

2.1 Biology and Biotechnology at WPI

2.1.1 Biology and Biotechnology Department Goals

The primary focus of the Biology and Biotechnology Department at WPI is to make scientific and technological advances that also address the needs of society. It is the department's objective to prepare well-educated students to be able to approach problems with creativity and flexibility. One of the key focuses in this preparation is active participation in the scientific process ("2016-2017 Undergraduate Catalog").

The department's program is founded on five concepts of biology: the first, that all living things evolve through different processes like genetic drift and natural selection, that all biological systems follow the principles and laws of both chemistry and physics, that the simpler biological units are capable of assembling into more complex systems, biological systems function via the actions of regulatory systems, and that scientific knowledge requires hypothesis testing and observation. Understanding these concepts provides students with the foundation of biotechnology. Biotechnology is considered the "technological application of biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use." (United Nations Convention on Biological Diversity) In the curriculum, the five concepts are integrated throughout the department's three major divisions of biology: cellular and molecular biology, biology of the organism, and organisms in their environment ("2016-2017 Undergraduate Catalog").

The program's learning outcomes are designed to support life-long learning in the biology and biotechnology. Graduates are expected to know and understand the five unifying

concepts, and explain examples of each within the three divisions previously mentioned. Students also demonstrate a mastery of a range of skills, both quantitative and procedural, that are applicable to research and practice in their field. They are able to generate hypotheses, design approaches to test them, and interpret data to reach valid conclusions. Students that graduate from WPI are expected to have the ability to find, read, and critically evaluate scientific literature, describe the broader scientific or societal context of their work, collaborate well, and demonstrate their communication skills orally and written. Finally, these students also understand and adhere to accepted standards of intellectual honesty throughout their academia (“2016-2017 Undergraduate Catalog”)

2.1.2 The BB2900 Introductory Laboratory Series

The laboratory courses provided at WPI provide foundational skills needed for the study of living organisms and systems at the molecular, organismal, and environmental level. In these labs students begin building the skills they need to carry into more advanced labs, their MQPs and professional careers. In particular, students gain experience with scientific procedures and techniques, technical equipment, teamwork, laboratory safety, hypothesis generation and testing, scientific data analysis (including statistics), as well as oral and written scientific communication and skills. These experiences prepare them for their future at WPI, as well as their future post-graduation (Buckholt, 2016).

2.2 BB2901: Molecular Biology, Microbiology, and Genetics

BB2901: Molecular Biology, Microbiology, and Genetics covers the basic laboratory techniques and knowledge needed for a future career in biotechnology and those intending to pursue a health profession. Examples of the types of techniques and experiences included in this

course are: the use and handling of bacteria in the laboratory, identification of bacteria through staining and metabolic testing, aseptic technique, and microscopy (Buckholt, 2016).

The objective of this course is to provide a variety of opportunities for students to learn and develop laboratory and writing skills important in their major. These skills will be useful in both MQP work and in the more advanced biology labs. Completing this course increases students' competence in scientific writing and managing, organizing, and analyzing data. BB2901 also offers students the chance to collaborate more effectively with other students, gain knowledge on biology topics, and observe biological principles and theories throughout their laboratory work (Buckholt, 2016).

The class typically meets twice a week. The first meeting is in a large-lecture style format. It is a 50 minute class period in a lecture hall, where important laboratory information for the week is reviewed, and the two quizzes throughout the term are administered. The second meeting is the laboratory period itself. This typically runs for an hour and 50 minutes, and is completed in smaller laboratory sections. Students work collaboratively with one other student throughout the term (Buckholt, 2016).

Pre-labs are utilized in this lab, and contain 7 points for questions and 3 TA-awarded subjective points. The TA evaluation points are awarded on the basis of arriving to lab on time, being prepared for lab, cleaning up after lab, working well with others, and respectful and responsible lab behaviors. Each lab experiment will have a pre-lab assignment associated with it that must be completed before coming to lab, and is done individually. The pre-labs each week are in the form of an electronic Blackboard quiz that must be completed before the scheduled lab time begins. This set of questions is meant to get students thinking about the lab, and make sure that they have made an effort to prepare for it before they arrive. The questions are mostly

multiple choice, but there are also some short answer questions that are not graded immediately, and are later checked by the TA (Buckholt, 2016). There is no curve in this class, and grades are awarded as follows: A = (445.5-495 pts.), B= (396-445), C=(346.5-395) NR= \leq 346.5. These values come from the grading information below (Buckholt, 2016).

Grading:

Labs (Pre-lab, lab write up, TA)	80% of total grade
Quizzes approximately	20% of total grade
Total	100%

Writing Assignments	5@ 45 points each	225 points
Lab 6 & 7 full report	1@ 90 points	90 points
Lab 1 Rubric Response	1@ 10 points	10 points
Prelabs	7@ 7 points each	49 points
TA evaluation	7@ 3 points each	21 points
Safety Agreement	1@ 10 points	10 points
<u>Quizzes</u>	<u>2@ 45 points each</u>	<u>90 points</u>
Total points		495 points

2.3 BB2905: Microbes to Molecules: Crowd-Sourcing Antibiotic Discovery

2.3.1 The Small World Initiative

The Small World Initiative (SWI) is a research collaborative that combines science education, scientific research, and science diplomacy to college classrooms (“Small World Initiative”). Students involved in this program have the opportunity to address a worldwide health threat as well as work to find a solution. This threat is the diminishing supply of antibiotics

worldwide. Students involved in SWI collect soil samples from local environments prior to the course, and are then challenged to discover any new antibiotics produced by soil bacteria from said samples. Once the soil has been collected, they isolate any diverse bacteria, test said bacteria against microorganisms that are clinically-relevant, and then characterize those showing inhibitory activity. This initiative integrates antibiotic discovery with foundational biology concepts to create different courses, specifically in cellular and molecular biology. The microbe data can be found on an online database, and provides leads for antibiotic producers and those interested in development of future drugs, while also providing students with a unique learning experience and an engaging introduction to biology laboratory techniques (“Our Approach”).

Since 2012, when the program was initiated at Yale University, the SWI has held training workshops and created over 100 partnerships with different universities throughout the United States and in nine different countries around the world. The SWI network includes: sixteen research universities with high research activity; nine liberal colleges; six community colleges; and sixteen international schools. The SWI was inspired by the “Engage to Excel” initiative set forth by Barack Obama in 2012. The primary goal of “Engage to Excel” is to see a 33% increase in the number of STEM bachelor’s degrees completed per year in the United States, and the recommendation is to do so by engaging students in compelling experiments with real-work applications and the potential for true discovery (PSCAT, 2012). The scientific goals of SWI align with those of “Engage to Excel” and include: addressing the global concern for antibiotic resistance, discovering potential natural product antibiotics, and exploring the microbial and biochemical diversity of the soil around us that has yet to be researched.

2.3.2 The Course Implemented at WPI

Using the curriculum set forth by the Small World Initiative, students enrolled in this course gain skills in the process of scientific inquiry and in common procedures of microbial culture and characterization. Upon completion of this laboratory, students report their findings in a poster-style format, and are able to see the results of other groups within their class, as well as around the country (Buckholt, 2015).

This course provides students with the opportunity to develop their laboratory and written skills sets which will prove to be beneficial in their future endeavors, both at WPI and after graduation. The specific learning goals that this laboratory provides students the opportunity to master are: the ability to describe the nature of science as a discipline, the practice of safety measures while working with hazardous materials; the ability to explain the scientific process and provide examples from their experiences (written and oral); gain proficiency in laboratory techniques; broadly discuss microbial diversity; and develop an understanding of microbial ecology, specifically as it pertains to soil as an ecosystem. Students also have the opportunity to demonstrate their analytical skills, as they are expected to mathematically and statistically process, summarize, graphically present, and evaluate their hypotheses. Those enrolled in BB2905 work with several different culturing conditions and media types in order to successfully grow microorganisms. They study the ESKAPE (*Enterococcus faecium*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, and *Enterobacter* species) pathogens, their relatives, and how they are related to infectious disease. Students also utilize a variety of different resources for their final project, study ethics, and demonstrate basic skills in microscopy. One of the primary learning goals achieved in this course is an understanding of the function of antibiotics, and their role as

secondary metabolites, and the techniques necessary to isolate them. Students that complete this course are also able to define and provide examples of evolution, selection, competition, and antibiotic resistance through their research and laboratory classes (Buckholt, 2015).

One of the major differences between BB2901 and BB2905 in terms of structure and course set up is the use of LabArchives in the BB2905 laboratory. As opposed to requiring a textbook for lab procedures, or keeping a lab notebook on-hand and writing formal lab reports, students are required to create a LabArchives account. LabArchives Classroom Edition is the number one Electronic Notebook (ELN) designed for professors to engage, monitor, and evaluate student's laboratory work. Because LabArchives is a cloud-based network, it can be accessed on any device ("LabArchives Electronic Notebook"). Access to a computer with internet is the only thing required of students, and computers as well as iPads are provided in the lab. BB2905 does not require any formal lab reports, however, students' online lab notebooks are expected to be very detailed. Any other assigned work in the course is also put into LabArchives. Paper documents can be uploaded as scanned documents or photos using LabArchive's free mobile app, and therefore, it is suggested that students also take their original data down on a piece of paper that can be easily scanned or attached to their electronic notebooks. One of the benefits of this forum is the value behind not removing notebooks or data sheets from a microbiology laboratory, where contamination is possible in transference of paper and the use and observation of different bacteria.

There are no curves in this class, and grades are awarded as follows: A = (490.5-565 pts.), B= (436-489), C=(381.5-435) NR=<381.5. The grading distribution for the class can also be seen below:

Grading:

Blackboard prelab quizzes	~20% of total grade
Notebook assignments	~20% of total grade
Lab notebook record keeping	~20% of total grade
Poster presentation related assignments	~30% of total grade
Poster and research help sessions	~5% of total grade
Laboratory Skills and participation grade	~5% of total grade
Total	100%

Blackboard quizzes	9 @ 10 points each	90 points
Notebook assignments	9 @ 10 points each	90 points
Lab notebook maintenance	7 @ 15 points each	105 points
Poster and research help sessions	2 @ 15 points each	30 points
Poster draft	1 @ 30 points each	30 points
Peer poster evaluation	1 @ 30 points each	30 points
Final poster and presentation	1 @ 120 points each	120 points
Safety Agreement	1 @ 10 points	10 points
Homework	1 @ 10 points	10 points
<u>Laboratory Skills and Participation</u>	<u>1 @ 30 points</u>	<u>30 points</u>
Total points		545 points

(Buckholt, 2015)

The goal of this project is to develop a laboratory course curriculum, combining two current courses, BB2901 and BB2905. To accomplish this goal, the specific objectives are to: develop a comprehensive assessment of new, and effective approaches to science education, specifically in a laboratory setting; characterize the key objectives of each individual laboratory course, and combine the curriculum in a way such that all objectives are still met, and work cohesively in

one course; analyze the data obtained from student surveys; and recommend a course curriculum based on the information obtained in the above objectives. This project is addressing a need, as the Biology and Biotechnology Department is implanting a new course curriculum combining these classes that will be implemented for the first time in the 2017-2018 school year.

3. Methodology

Objective 1: Comprehensive Assessment of New and Effective Approaches to Science Education

An extensive review of research literature, including reputable academic journal articles, relevant books, scholarly websites, and other pertinent materials was performed in order to identify new and effective approaches to science laboratory education. This literary research is included in the Literature Review section starting on page 5. The sections are broken down by journal article, and then an analysis and summary of the material is located in the Findings section.

Objective 2: Characterization of Key Objectives in Each Laboratory Course

The instructor's course materials for both BB290X and BB2901 was reviewed, and main objectives of both laboratory courses were identified. The lab manuals for each particular lab period was also be reviewed. After doing so, common objectives throughout both courses were identified, and this information was used to create a curriculum that works cohesively, and covers all topics necessary.

Objective 3: Conduct Online Student Survey and Analyze Data Obtained

A short, online survey was sent to students who were previously enrolled, or are currently enrolled in either BB2905(X) or BB2901. This survey was conducted in order to gain

students' insight into the current biology laboratory formats, and what they would like to see happen in the future. The stakeholders in this scenario are the students who have taken these two courses already. Their first-hand experience in laboratories provided a new insight into changes they would like to see, as well as what they deem most beneficial in terms of formatting the course.

The survey was sent out via email, and the questions were developed based on prior knowledge of the biology laboratory course schedules. The survey questions can be seen in Appendix B, along with the email sent out to previously enrolled students (Appendix A). The questions are meant to determine what class schedule structure students find most beneficial to their learning process, and what term-schedule they would like to see if this curriculum was put into effect in the near future.

With respect to the method of the survey, a list of students' emails was obtained, including any student who was registered for either BB2905(X) or BB2901 in the past three years. Three years ensures that the people included in the survey are currently enrolled students. Prior to the start of the survey, there is a section informing the subject about the purpose of this project. It was noted that participation in this survey is voluntary, and that responses to said survey will remain anonymous. Students were given three weeks to submit the survey, during which time, a secondary email was sent out in order to ensure more responses.

Objective 4: Create Recommendations for the New Course Curriculum

All of the information collected in the literature research, curriculum research, and survey questions has been synthesized to ascertain a comprehensive and effective recommendation for a course curriculum that can be applied in the years following.

4. Findings

4.1 Literary Review and Implications in Redesigning the Course Curriculum

A common theme throughout nearly every paper in the literature review was the concept that explicit instruction and practice in experimental design is often lacking in introductory life science courses and laboratories. There are many reasons why this may be the case, however more often than not it is because of perceived time pressures, large class sizes, and need to emphasize content as opposed to skills (Brownell, 2013).

The 2900 level laboratory courses at WPI are not structured in this manner, and for this reason, an issue that is so prominent at most universities does not seem to be one at this school. While lectures may be larger, the labs are split into sections so there are on average, 14 students per lab section. In addition to the small number of students in each section, there is also typically one lab instructor as well as a TA in the lab to clarify any information, and make sure the lab is safe and running according to schedule.

One researcher, in particular, provides four key components for effective interactive engagement. They are extensive structuring of learning tasks by the teacher, strongly interactive student-student execution of the tasks, effective debriefing or other assessments that provide prompt feedback to the teacher as to the extent that the intended learning succeeded, and instructional modifications by the teacher that take account of this feedback (Nelson, 2008).

The professors who made the curriculums for BB2901 and BB2905 have created extensive course structures that provide very clear and concise objectives, and expectations, while also engaging students in interesting and applicable laboratory experiments. Students work in the 2900 level labs in groups of two, and in this way there is a strong interactive student-

student execution of all tasks, with the exception of lab reports and pre-labs, which are written and submitted separately. Professors in the biology department obtain prompt feedback as to the success of the learning objectives for each lab period through the writing of pre-labs, online quizzes, written lab reports, and projects. If any pertinent topics seem to be missed amongst a majority of the students, or even just a few, professors and instructors are able to make not of the situation and modify if necessary, whether that be a clarifying conversation, or the ability to change a course objective or activity in order to benefit the students' understanding.

4.2 Key Objectives of Each Laboratory Course and Scheduling

4.2.1 BB2901: Molecular Biology, Microbiology, and Genetics

The timeline below in Figure 1 serves as a the week-by-week schedule for the BB2901 course, and this information along with the timeline for the BB2905 course will prove to be integral when providing recommendations in course structure (Buckholt, 2016).

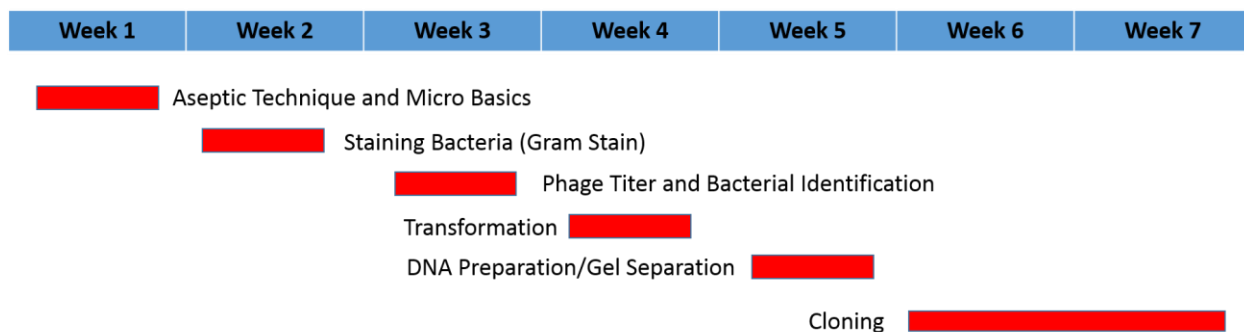


Figure 1: Week-by-week schedule of laboratory experiments completed in BB2901

4.2.2 BB2905: Microbes to Molecules: Crowd-Sourcing Novel Antibiotic Discovery

The timeline in Figure 2 (below) is similar to Figure 1, but since the course structure is more fluid; there is more overlapping from week-to-week. According to the lab manual, there is a set list of experiments to be completed each week, and these can be seen in more detail in the Small World Initiative Student Research Guide. In week one, students are expected to complete

experiments 1 and 2, which includes devising a method to transfer microbes from a soil sample to a medium in the lab, find a local soil environment from which to sample from. In week two, Experiments 3 and 4 are conducted, and involve finding a method to isolate single colonies from soil samples and choosing a media as well as culture conditions. Week three involves Experiments 5 and 6, during which time students are expected to isolate unique colonies to test for antibiotic production, and gain an understanding of the ESKAPE pathogens, and using safe relatives in the laboratory. During week four, both lab periods are typically spent designing a method to screen for antibiotic producers (Experiment 7), and in week five students begin Experiments 8 and 9. Experiment 8 involves the initial identification of antibiotic-producing isolate, and Experiment 9 is conducted in order to test the isolate's organic extract for antibiotic activity. In week 6, students begin Experiment 11, which involves the biochemical characterization of isolates, and one of the lab periods is used to edit the posters students have been working on throughout the term. The last week of the term (week 7) students are expected to finish Experiment 11 and any others they have yet to conclude, and go over the results of the Experiment 8 and BLAST searching. The last day, in lieu of another laboratory, there is an evening poster presentation of students' findings throughout the term (Buckholt, 2015).

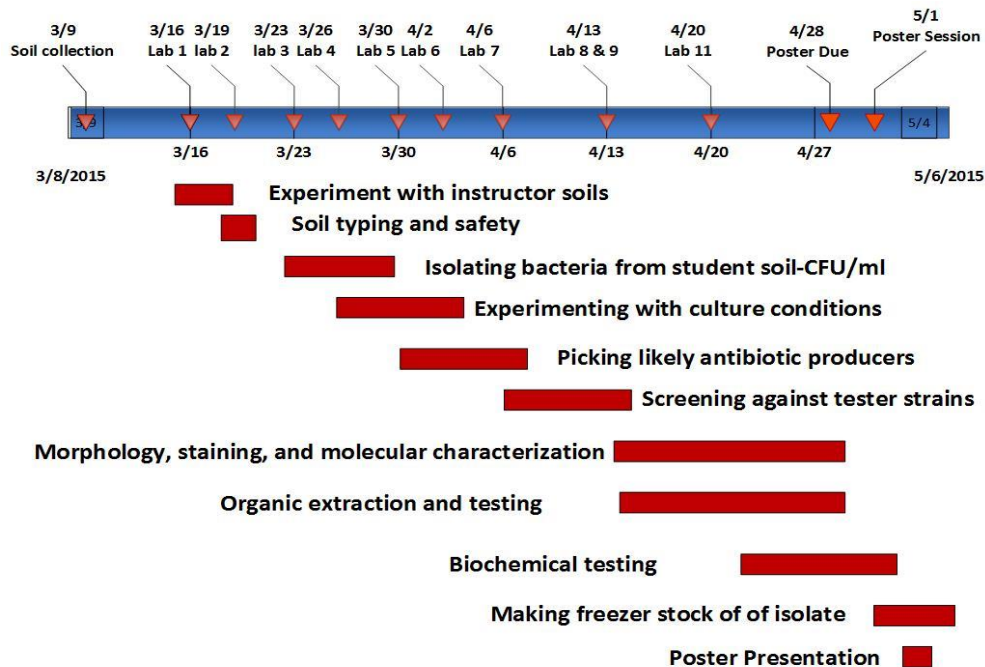


Figure 2: Week-by-week schedule of laboratory experiments completed in BB2905 (Buckholt, 2016)

4.3 Survey Responses

Figure 3 below shows the major distributions amongst the students who completed the survey. While this question was asked, the response was not required, in order to give each student complete anonymity. Therefore, only 30 out of the 61 students surveyed responded to this question. Out of those 30 students, 18 were Biology and Biotechnology majors, 3 Biomedical Engineering, 6 Biochemistry, 2 Chemical Engineering, and 1 Chemistry.

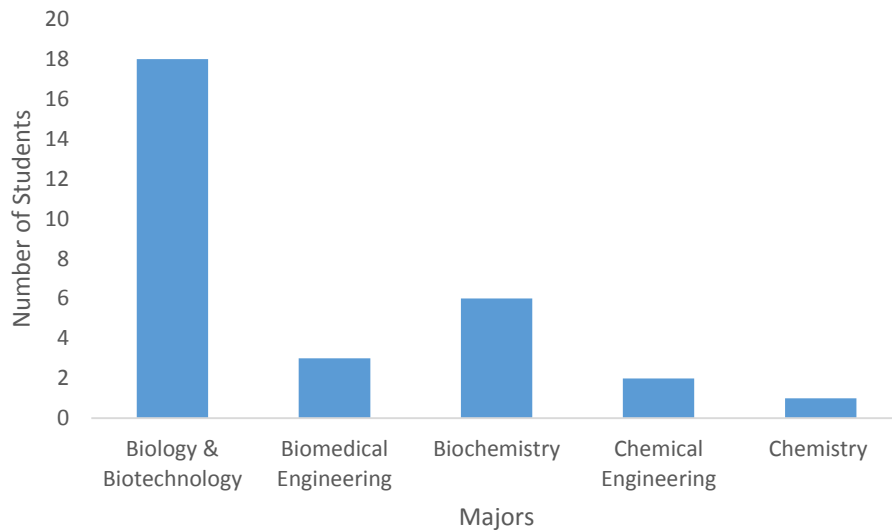


Figure 3: Major distribution amongst surveyed students

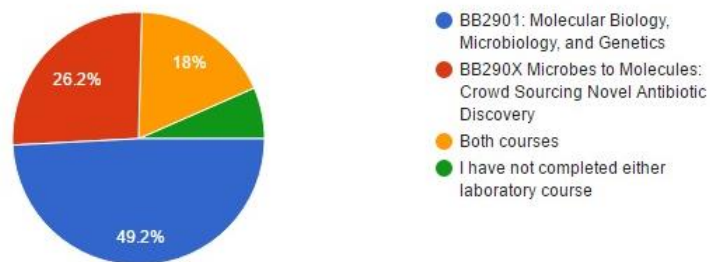


Figure 4: Laboratory courses completed by surveyed students

Figure 4 above shows the percentage of students who have completed one, both, or none of the laboratory courses involved in this project. As you can see, only 18% of students have taken both. That is most likely because Biology and Biotechnology majors could not get laboratory credit for both courses when this survey was taken, however, that has changed in the past school year.

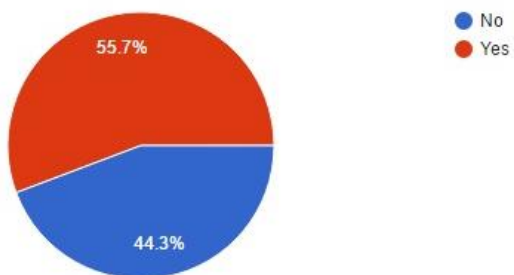


Figure 5: Student response to “have you ever completed a 3000 level biology laboratory course at WPI?”

Figure 5 above shows the percentages of students who have taken a 3000 level Biology laboratory at WPI (yes), and those who have not (no). This information is pertinent because 3000 level laboratories typically meet only once a week for a three-hour laboratory session, as opposed to the BB2901 format in which there are two scheduled days of class. The first day is a 1 hour lecture, and the second is a two hour laboratory session. BB2905 is more lab-intensive, and meets twice a week for two hour periods of time. For this reason, students who have taken a 3000 biology laboratory (and presumably a 2900 level laboratory) may provide helpful insight into student preference on length and frequency of laboratory sessions, and the weekly structure of the course. If students responded “yes” to the previous question, they were then asked which weekly schedule they found most beneficial to their learning experience. This data can be seen below in Figure 6.

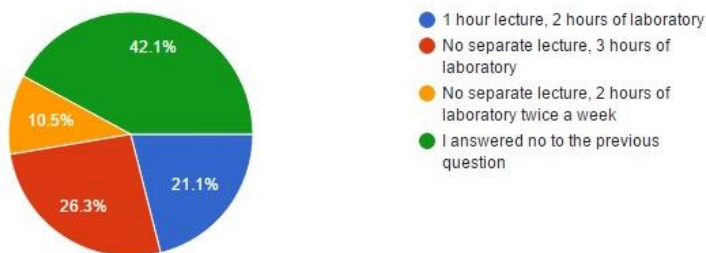


Figure 6: Student preference on class schedule

Figure 6 shows student responses to their preference in class meeting times and format on a weekly basis. The majority of students (42.1% of the 61 students surveyed) answered no to the previous question, meaning they had never taken a 3000 level biology laboratory courses. However, out of the students who had, the majority (26.3%) preferred the 3000 level set up, in which there is no separate lecture, and there is one lab per week that lasts for a total of three hours. Students were then asked to explain their preference and leave comments if they so desired. This data can be seen below in Table 1.

Table 1: Student comments on class schedule preference

Student Preference	Students' Comments
Neither	I've had several labs involving lecture during the first hour, and I don't like it that way. I prefer to have the lab period to complete the assigned work, and also did not find the lectures helpful either.
No separate lecture; 3 hours of lab once a week	I believe the lectures do not provide insight in the content of the course. Having lab once a week for 3 hours allows for in-lab lecture time and plenty of time to complete weekly lab reports.
No separate lecture; 3 hours of lab once a week	The separate lecture isn't as important when the professor typically lectures in lab prior to the start. Having lab more than once a week is not bad, but the lab should be three hours in order to have a more complete lab. Two hours is not enough time.
1 hour of lecture; 2 hours of laboratory	Having a lecture is nice because it allows time to learn key concepts, enhancing understanding when experiments are actually being done.
No separate lecture	A few tips or reminders prior to the start of lab is helpful, but a designated lecture section is often not necessary.
No separate lecture; 3 hours of lab once a week	3 hours of lab is enough time for an explanation of the lab as well as to complete most laboratory experiments

Students were then asked about the pre-lab format they found most beneficial to their learning. The options were written pre-labs to be submitted prior to the start of each laboratory session, online pre-lab quizzes administered on either myWPI or Canvas, and there was also a no preference option as well. It can be seen in Figure 7 below that the majority of students surveyed

(49.2%) preferred the online quiz pre-labs opposed to the written pre-labs. Students were then asked to explain their opinions if they so chose, and this data can also be seen below in Table 2.

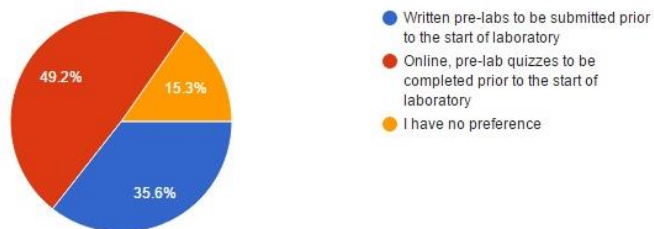


Figure 7: Student preferences on pre-lab formats

Table 2: Student comments on pre-lab structure

Student Preference	Students' Comments
Written pre-labs	While way more work, allowed for easier lab experience, since you had to read the lab manual fully at least once
Online quizzes	Online quizzes encourage understanding of the material without requiring too much before the lab even starts
Written pre-labs	I learn much more from the pre-labs I submit for my 3000 level courses. Though they are more time consuming, they aid in the understanding of the content completed in the upcoming lab.
Online quizzes	Online pre-labs are easier to complete. You can also get answers before going to lab which can help you understand a concept you don't feel comfortable with
Online quizzes	It is more helpful to let us actually test our own understanding of the material rather than write something out and hope that it's right
No preference	They both have advantages and disadvantages; quizzes tend to focus more on the concepts at hand and written pre-labs tend to focus on experimental procedures themselves.
Written pre-lab	A written pre-lab forces me to prepare a little bit more
Written pre-lab	Online quizzes are done as quickly as possible. Usually the answers can be googled, and do not require a whole lot of work. The written pre-labs, while sometimes unnecessarily long, require the student to set up tables and procedures so the lab and data collection will go smoothly.
Online quizzes	They are quick and easy to do, but also have questions that are detailed enough that students have to pay attention to the reading in order to get the answers right.

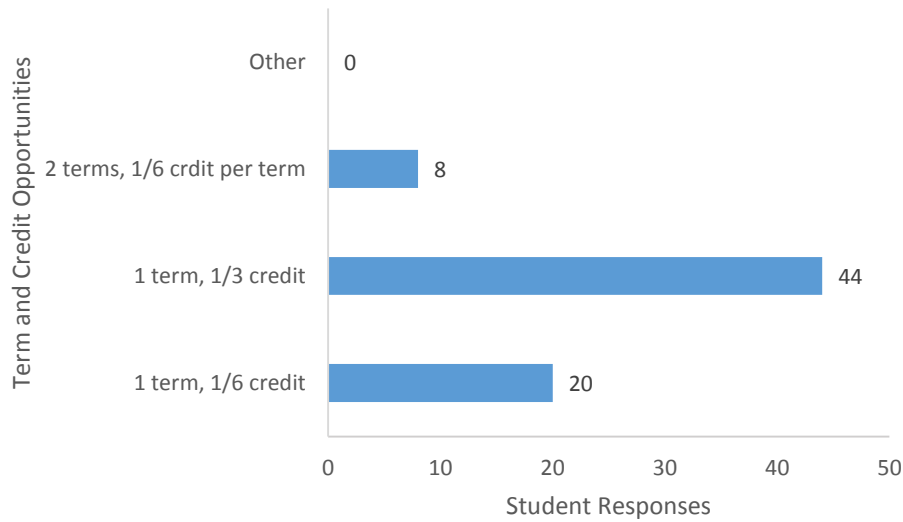


Figure 8: Student preferences on term and credit distribution

Figure 8 above shows students' responses to credit distribution and term scheduling. It is very evident from looking at the data that students would prefer a biology laboratory class that runs for one term, and is $\frac{1}{3}$ of a credit. Below, in Figure 9, students were asked whether or not they would utilize open lab time if it was made available during the week, and an overwhelming number of students reported that they would.

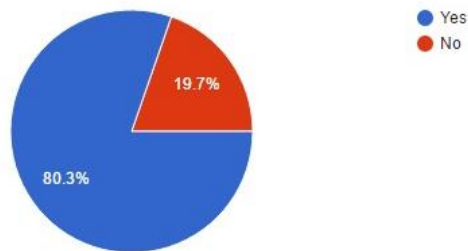


Figure 9: Response to the following question: "if open lab space was provided throughout the week, would you utilize it?"

5. Conclusions and Recommendations

5.1 Use of New and Effective Approaches to Scientific Education

The objective of this project was to propose a redesigned course curriculum, combining biology laboratories BB2901 and BB2905. From the findings section and the scientific literature used in research, it has been determined that these two courses are already ahead of many programs. The WPI Plan, and WPI's commitment as a university to promote project-based learning as a way to stimulate and engage STEM students is exactly the kind of laboratory setting that will help achieve the goals set forth as a country in "Engage to Excel." While introductory courses, like 2901, may seem more routine than others, learning essential laboratory skills is absolutely paramount while pursuing a life sciences degree. However, combining this introductory course with BB2905 may further student interest since their new laboratory skills, particularly in microbiology, will be put to use in class throughout the term to solve a real-world problem.

5.2 Overall Structure of the Proposed Course

It is recommended, based on student feedback and prior research, that the new course be carried out in one term, and count for 1/3 credit, as opposed to 1/6. Because of the change in crediting, there will also be an increased workload and increased time spent in laboratory throughout the term. It is suggested that the new course meet three times a week, for two hour laboratory sessions. The days and time of the week this occurs will be dependent upon laboratory scheduling completed by the instructors of the course. Open lab space is another recommendation that student surveys indicated may be beneficial to learning and succeeding in this course.

LabArchives will be more readily used in this laboratory course because documents that may have previously been submitted on Canvas or myWPI, for example laboratory write-ups and pre-labs, can now be submitted to LabArchives. It will serve as the primary forum for students to use throughout the course. This provides an added benefit because all lab protocols can be referred to on the site, and therefore, students will not be transferring bacteria outside of the lab when working with microbes.

5.3 Proposed Week-By-Week Schedule

The proposed weekly schedule seen below was created by combining the weekly BB2901 schedule, and the BB2905 schedule. It includes the three days each week the course will meet, and the experiments students will be expected to complete during this time.

After reviewing both courses, and their laboratory manuals and protocols extensively, it was evident that it would be beneficial for students to be introduced to new skills on the first day of each week (using the BB2901 procedures currently in place), and then the following two days will be used to work on the BB2905 microbes to molecules project created by the SWI, and implemented at WPI. While there may be some overlap in certain skills, it is at the instructor's discretion whether or not certain procedures in each lab period may be combined. For example, in the lab 3 procedure in BB2901: Molecular Biology, Microbiology, and Genetics, students learn how to identify unknown bacteria using physiological tests and morphology (Buckholt, 2016). This is a skill crucial in the BB2905 course, and there may be a way to combine the two lab periods, however, it is recommended this decision be brought to the attention of instructors, but not implemented immediately so that no pertinent laboratory skills are skimmed over or missed.

The BB2905 course is more fluid in terms of laboratory setting. Students are required to come up with their own ideas, hypotheses, and experiments in order to solve problems, while the BB2901 course is more strictly laid out so that students can master the basic laboratory skills that may be required in their future as scientists. With this being said, below, in Table 3 is the redesigned weekly course schedule for the new curriculum. Lab experiments and protocols are listed briefly, and assignments as well as their due dates are also included. Pre-lab formats and grading will be discussed in the next section. The gram stain laboratory (originally week 2) and the bacterial identification lab (originally week 3) were switched so that students could learn the basics of bacterial identification as they are creating their Microbes to Molecules projects.

Table 3: Term Schedule for Redesigned Biology Laboratory

Week	Day	Lab	Assignments	Day/Time Due
Week 1	1	Lab 1- Aseptic Technique and Micro Basics	Pre-lab 1	Prior to start of lab
	2	Experiment 1	Notebook submission 1	Prior to start of lab
	3	Experiment 2	Notebook submission 2	Prior to start of lab
Week 2	1	Lab 2 – Phage Titer and Bacterial Identification	Pre-lab 2 <i>Results Lab 1</i>	Prior to start of lab <i>Midnight</i>
	2	Experiment 3	Notebook submission 3	Prior to start of lab
	3	Experiment 4	Notebook submission 4	Prior to start of lab
Week 3	1	Lab 3 – Staining Bacteria (Gram Stain)	Pre-lab 3 <i>Results and Discussion Lab 2</i>	Prior to start of lab <i>Midnight</i>
	2	Experiment 5	Notebook submission 5	Prior to start of lab
	3	Experiment 6	Notebook submission 6	Prior to start of lab
Week 4	1	Lab 4 – Transformation	Pre-lab 4 <i>Results and Discussion Lab 3</i>	Prior to start of lab <i>Midnight</i>
	2/3	Experiment 7	Notebook submission 7	Prior to start of lab
Week 5	1	Lab 5 – DNA preparation/gel separation	Pre-lab 5 <i>Intro and References (Labs 6 & 7)</i>	Prior to start of lab <i>Midnight</i>
	2	Start experiments 8/9	Notebook submission 8/9 (combination)	Prior to start of lab
	3	Continue both experiments	<i>First draft of Poster</i>	<i>Midnight</i>
Week 6	1	Lab 6 – Cloning Part I	Pre-lab 6 <i>Results and Discussion (combo of labs 4&5)</i>	Prior to start of lab <i>Midnight</i>
	2	Start experiment 11	Notebook submission 9	Prior to start of lab

	3	Poster Review Session: meet in lab	<i>Peer Evaluations</i>	<i>In class</i>
Week 7	1	Lab 7 – Cloning Part II	Pre-lab 7 <i>Poster due for printing</i>	Prior to start of lab <i>3 pm</i>
	2	Finish experiment 11 and all others; go over results of experiment 8 and BLAST searching	Notebook submission 10	Prior to start of lab
	3	NO LAB; Poster Presentation Day	Time and Location TBD <i>Full Report for Labs 6&7</i>	<i>Last day of term</i>

5.4 Proposed Pre-Lab format and Grading

It is recommended written pre-labs replace the previously used online quizzes in the introductory laboratory sessions (first lab period each week). While this was not the popular opinion in the survey, it allows students to gain a better understanding of the background and protocols of the lab before it begins, and it can be submitted on LabArchives, while a quiz cannot. It is the goal to keep LabArchives as the primary submission forum in the course, and written pre-labs will aid in this. In addition, rather than completing pre-lab quizzes for the microbes laboratory sessions the following two laboratory period each week, it is also recommended that only notebook assignments be considered. The value of the pre-lab grades was also raised from 7 points to 10. More weight is put on these writing assignments because they are more writing-intensive than taking the online quizzes. Combining these courses and redesigning this laboratory meant certain portions of each laboratory course had to be cut so the work was manageable and still achieved the objectives of a WPI course in the Biology and Biotechnology department. For this reason, it was decided that the two quizzes from the BB2901 course would be cut from the curriculum. The first reason for doing this is because under this redesign, there is no longer a 50 minute lecture separate from the laboratory sessions, which is

when these quizzes are typically taken, and also because the writing assignments and poster project should be the focus, as well as completing all labs on time. Rather than have weekly TA evaluations valued at 3 points per lab, the 30 points for skills and preparation was adopted from the BB2905 original grading.

Grading:

Writing Assignments	5@ 45 points each	225 points
Lab 6 & 7 full report	1 @ 90 points each	90 points
Pre-lab write ups	7@ 10 points each	70 points
Notebook assignments	10@10 points each	100 points
Lab notebook maintenance	7 @ 15 points each	105 points
Poster and research help sessions	2 @ 15 points each	30 points
Poster draft	1 @ 30 points each	30 points
Peer poster evaluation	1 @ 30 points each	30 points
Final poster and presentation	1@120 points each	120 points
Safety Agreement	1@10 points	10 points
<u>Laboratory Skills and Participation</u>	<u>1 @ 30 points</u>	<u>30 points</u>
Total points		840 points

The new introductory biology laboratory course, combining BB2901 and BB2905, will be a part of WPI's curriculum beginning in the 2017-2018 school year. The research conducted and its results will hopefully aid in creating a collective and cohesive laboratory course curriculum that inspires and engages students in the STEM fields. In today's society there has been a call for scientists, and for society as a whole, to encourage research that gives us insight into the world, and solves real-world issues. As educators and as students in the STEM field that should be the ultimate goal, and that is what this proposed course promotes.

Appendix:

Appendix A: Online Biology Laboratory Survey Email

Good Afternoon,

If you are receiving this email it is because you were previously, or are currently, enrolled in either BB2901 or BB290X (now listed as BB2905).

We are currently working on an IQP project that will develop a new laboratory curriculum combining these two courses. Below is a link to a quick, anonymous survey.

https://docs.google.com/forms/d/16TS_22M5hpit1VCgQqXIFq8mNYcyXBxuNh4Fw-9Omqw/viewform

Your first-hand experience in one, or both, of these laboratory courses will provide us with insight into changes you would like to see, and any recommendations you may have as we move forward in this process.

If you so choose, you are also eligible to enter a raffle upon completion of this survey. The prize is a \$25 gift certificate to Dunkin Donuts.

Thank you so much for your participation!

Appendix B: Online Biology Laboratory Survey Introduction and Questions

Biology Laboratory Survey

Hello, and welcome to our Biology Laboratory Survey!

Thank you for participating! This survey will help us understand what changes students would like to see in biology laboratory courses, specifically in BB290X and BB2901.

Please note that participation is voluntary and responses will remain anonymous. You will also have the opportunity to enter a raffle after completing the survey. The prize is a \$25 gift card to Dunkin Donuts, and four winners will be chosen!

This survey should take no longer than 5 minutes.

Please click the "Next" button below to begin.

NEXT

 50% complete

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Google Forms

1. **What is your class year and major?**

2. **Please select the following laboratory courses you have completed at WPI:**

Mark only one oval.

- BB2901: Molecular Biology, Microbiology, and Genetics
- BB290X Microbes to Molecules: Crowd Sourcing Novel Antibiotic Discovery
- Both courses
- I have not completed either laboratory course

3. **Have you completed a 3000 level biology laboratory course at WPI?**

(Example: BB3511 Nerve and Muscle Physiology)

Mark only one oval.

- No
- Yes

4. **If you responded "Yes" to the previous question, which weekly class schedule structure did you find beneficial?**

Mark only one oval.

- 1 hour lecture, 2 hours of laboratory
- No separate lecture, 3 hours of laboratory
- No separate lecture, 2 hours of laboratory twice a week
- I answered no to the previous question

5. **Please explain your answer to the previous question:**

6. **In your previous experience, which pre-lab format do you find most beneficial to your learning process?**

Mark only one oval.

- Written pre-labs to be submitted prior to the start of laboratory
- Online, pre-lab quizzes to be completed prior to the start of laboratory
- I have no preference

7. **Please explain your answer to the previous question:**

8. **The laboratories BB2901 and BB290X will be combined to create a new, experimental course. What class schedule would you prefer?**

Check all that apply.

- 1 term: 1/6 credit, 2-3 hours of laboratory per week
- 1 term: 1/3 credit, 2-3 hours of laboratory twice a week
- 2 terms: 1/6 credit per term, 2-3 hours of laboratory per week
- Other

9. **If open lab space was provided throughout the week, would you utilize it?**

Mark only one oval.

Yes

No

10. **Thank you for completing this survey! If you would like to enter a raffle for a Dunkin Donuts gift card, please leave your name and email below.**

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