

EFFECTS OF INQUIRY BASED LABORATORY EXPERIMENTS ON STUDENTS'
COMPREHENSION OF BIOLOGICAL PRINCIPLES IN A UNIVERSITY LEVEL
BIOLOGY COURSE

by

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TABLE OF CONTENTS

INTRODUCTION AND BACKGROUND	1
CONCEPTUAL FRAMEWORK.....	3
METHODOLOGY	9
DATA AND ANALYSIS	22
INTERPRETATION AND CONCLUSION	31
VALUE.....	36
REFERENCES CITED.....	38
APPENDICES	40
APPENDIX A: Inquiry Lab I – Enzymes.....	41
APPENDIX B: Inquiry Lab II - Isolation and Identification of an Unknown Bacteria Isolated from Soil and Antibiotic Study	48
APPENDIX C: Scientific Method Lab.....	55
APPENDIX D: Enzyme Pre-Lab Quiz	56
APPENDIX E: Enzyme Post-Lab Quiz.....	58
APPENDIX F: Biology 231 Lab Exam 1, Treatment Question on Enzymes	60
APPENDIX G: Biology 231 Lab Exam 1, Non-treatment Question on Meiosis.....	63
APPENDIX H: Antibiotic Pre-Lab Quiz.....	65
APPENDIX I: Antibiotic Post-lab Quiz	67
APPENDIX J: Experimental Design Grading Rubric - Inquiry Lab I & II.....	69
APPENDIX K: Formal Report Grading Rubric – Enzymes.....	71
APPENDIX L: Formal Report Grading Rubric – Antibiotics.....	74
APPENDIX M: Biology 231 Lab Exam 2, Treatment Question on Antibiotic Resistance & Sensitivity	77

LIST OF TABLES

1. Outline of Treatment vs Non-Treatment Control Laboratories in Biology 231	18
2. Triangulation Matrix	19
3. Comparison of Antibiotic Examination Question Data: Traditional Non-Inquiry Antibiotic Experiment vs Inquiry Antibiotic Experiment	30

LIST OF FIGURES

1. Percentage of Students Showing Change in Conceptual Knowledge Following Inquiry Experiment on Enzymes	23
2. Frequency of Students Showing Increases in Conceptual Knowledge of Enzymes Following Treatment Unit	24
3. Comparison of Average Student Grades on Inquiry Lab I - Treatment and Non-Treatment Examination Questions and Overall Lab Examination Scores with Accompanying Standard Deviations	25
4. Percentage of Students Showing Change in Conceptual Knowledge Following Inquiry Experiment on Antibiotics.....	27
5. Frequency of Students Showing Increases in Conceptual Knowledge of Antibiotics Following Treatment Unit	28
6. Comparison of Average Student Grades on Inquiry Lab II - Treatment and Non-Treatment Examination Questions and Overall Lab Examination Scores with Accompanying Standard Deviations	29

ABSTRACT

This study investigated the effects of implementing inquiry based experimentation in the laboratory portion of a first year university level general biology course. Students designed and performed their own experiments on two major biological topics. Data indicated that students acquired more comprehensive knowledge of the biological principles studied when they engaged in their own learning and designed their own experiments. Their report writing skills improved as did their understanding of scientific method. The time spent on the inquiry projects encouraged students to form collaborative work partnerships and work together outside of class time. Students participating in the study showed improved comprehension of the topics studied using inquiry based learning methods when compared to topics studied in the laboratory using traditional non-inquiry based learning methods.

INTRODUCTION AND BACKGROUND

Medicine Hat College (MHC) is located in Medicine Hat, Alberta, Canada. There are 5,408 students enrolled at the college (M. Blair, personal communication, May 9, 2012). Medicine Hat College draws students from the city of Medicine Hat and from ranching communities and farms across southeastern Alberta and southern Saskatchewan. There are over forty programs offered at MHC. Programs range from university transfer programs, applied degrees, Apprenticeship and Trades programs and degree programs in Commerce, Education, Nursing and Social Work (Medicine Hat College, 2012). Demographics are not recorded at Medicine Hat College however a geographical source study of students indicate that 4.9 % are international students and 32 students are self-identified Aboriginal (M. Blair, personal communication, May 9, 2012). This is similar to that of the city of Medicine Hat, which has a population of 72,807 (Statistics Canada, 2012) with 3.3 % of the population being of visible minority (Statistics Canada, 2007).

I am a microbiology laboratory instructor in the University Transfer (UT) Science Program for the Department of Science at MHC. The UT Science program is a two-year program that enables students to complete the first two years of university level science courses before transferring to university to complete their degrees. One of the courses I teach is the laboratory portion of Biology 231, a first year undergraduate general biology course. Students in the course are registered in a wide variety of programs including Science, Nursing, Arts, Education and Commerce (Medicine Hat College, 2012).

Registration in the course consists of approximately one hundred and twenty students in the fall term and fifty students in the winter term. Over the past thirty years of teaching I

have noticed that students who pass Biology 231 demonstrate an increasing lack of knowledge of basic biological principals in second year biology courses. Most students who enter my Cellular and Molecular Microbiology course in their second year at MHC struggle because they do not remember basic biological, chemical and mathematical principals that they were taught in their first year prerequisite courses including Biology 231. The majority of my students have no recall of the microbiological principals and laboratory techniques that they performed well enough to pass Biology 231 when they enter CMMB 343. Consequently I lose a considerable amount of valuable laboratory time re-teaching topics and lab techniques from Biology 231 before I can start teaching CMMB 343 course material. My concern over my students' poor retention of subject matter from first year courses motivated me to find ways to improve their long lasting learning of biology. I was also concerned with the lack of report writing skills that students demonstrated in advanced courses. I felt that having students do formal scientific reports would improve their report writing skills.

My project focused on the effects of implementing inquiry based laboratory experiments into Biology 231. My action research project focus question was: What are the effects of inquiry-based laboratory experiments on students' comprehension of biological principals in a first year university level biology course?

CONCEPTUAL FRAMEWORK

Inquiry based learning has become a growing trend in science education reform over the past two decades. Traditional methods of teaching and learning science are changing based on the National Science Education Standards which emphasize using inquiry based methods to teach science to students from grades K-12 (NRC, 1996). The philosophy is that “Students’ understandings and abilities are grounded in the experience of inquiry and inquiry is the foundation for the development of understandings and abilities of the other content standards” (NRC, 1996, p. 104). Science educators recommend that science should be taught to students in an active investigative manner similar to the types of inquiry based research methods that scientists use in their own work (Lunsford & Melear, 2004). Post secondary institutes are slowly starting to implement pedagogical reforms involving inquiry methods to both lecture and laboratory portions of science courses (Basey, Mendelow & Ramos, 2000; Ebert-May, Brewer & Sylvester, 1997; Gormally, Brickman, Hallar & Armstrong, 2011; Timmerman, Strickland & Carstensen, 2008).

Inquiry based education changes the focus of instruction from teacher driven to student learner and forces the student to become an active rather than passive participant in his/her learning experience. (Ebert-May et al., 1997; Lord & Orkwiszewski, 2006). The traditional method of teaching sciences in post-secondary laboratories involves students performing laboratory experiments in a cookbook fashion with instructors directing them in experiments that have pre-determined hypotheses and conclusions

(Herron, 2009; Huddleston & Addy, 2005; Lord & Orkwiszewski, 2006). Lecture and laboratory portions of university and college science courses involve strict memorization of many facts where students are assessed by regurgitating the facts. In laboratory courses, students are required to copy down lab procedures from a lab manual, perform calculations with formulae given to them by the instructor and answer laboratory questions by paraphrasing sections of the lab manual. Laboratory assignments involve lab reports written following traditional formats where predetermined theories are proven and no critical thinking or experimental design skills are required or developed (Huddleston & Addy, 2005; Lord & Orkwiszewski, 2006). Laboratories taught in this manner turn “students into technicians, not scientists” (Polacek & Levine Keeling, 2005, p. 52). Students are able to sit passively in lectures and labs and mentally tune out or turn off, doing very little active learning (Lord & Orkwiszewski, 2006). Faculty recognize that students taught using these methods are not able to think independently, have few problem solving skills, and do not have a thorough understanding of basic scientific principles (Timmerman et al., 2008).

Inquiry based learning provides students with challenges that motivate them to become active learners in their own education (Lord & Orkwiszewski, 2006; Timmerman et al., 2008). Inquiry activities promote more meaningful and deeper student understanding of scientific principles (Lord & Orkwiszewski, 2006; Timmerman et al., 2006).

Inquiry learning also increases student awareness and critical thinking (Polacek & Levine Keeling, 2005) and results in more complete, longer term learning because students need to be both mentally and physically involved in their own active learning

process (Lord & Orkwiszewski, 2006). Llewellyn comments, “scientific inquiry focuses on the engagement of students to generate and pursue the answers to questions through careful observation and reflection” (Llewellyn, 2005, p. 3).

There are many methods of incorporating inquiry into science education. The National Research Council lists twelve recommendations for promoting inquiry in science teaching (NRC, 1996). They recommend placing less emphasis on traditional methods of teaching science and more emphasis on activities that involve the student as an active learner involved with the instructor in the learning process. They emphasize methods that encourage the student to develop and use the same thinking and analyzing skills that scientists use to investigate and solve alternate hypotheses and theories in their everyday research (Lunsford & Melear, 2004; NRC, 1996, p. 113). Educators differ as to what comprises inquiry based learning and teaching and how it should be implemented into post-secondary lectures and laboratories (Basey, Mendelow & Ramos, 2000; Lunsford & Melear, 2004). The basic premise is that experimentation and learning is student driven (Polacek & Levine Keeling, 2005). The instructor acts as a facilitator rather than a leader. Students direct their own research into problems and solve them.

Inquiry in laboratory courses is achieved through “open-ended laboratories that allow students freedom to define the problem, methods, solutions, and extensions” (Basey et al., 2000, p. 80). Different educators in post secondary settings teach inquiry in lecture and laboratory settings in different ways. Methods such as traditional inquiry, open inquiry, directed inquiry, authentic inquiry, collaborative inquiry, cooperative learning and purposeful inquiry are just some of the many terms applied to teaching methods (Buck, Bretz & Towns, 2008; Ebert-May et al., 1997). A couple of these

methods are most commonly used in post secondary laboratory courses. Open inquiry involves students directing an entire project, coming up with a problem and solving it with the instructor serving as a facilitator but not directing or influencing the project (Basey et al., 2000; Gormally et al., 2011; Herron, 2009; Udovic, Morris, Dickman, Postlethwait, & Wetherwax, 2002). There are several variations of open inquiry; open induction where students direct the entire project and open-ended inquiry where students direct the project but also receive some assistance in terms of “methodologies and experimental protocols” (Basey et al., 2000, p. 80). Guided inquiry is another type of inquiry that involves the instructor giving students an initial problem as well as providing them with some direction and tools to solve their problem. The student has to use some independent thinking and experimentation techniques to complete the project (Basey et al., 2000; Gormally et al., 2011; Huddleston & Addy, 2005; Lord & Orkwiszewski, 2006; Polacek & Levine Keeling, 2005). Guided inquiry is more useful for students that lack the educational experience and abstract thinking skills required for conducting open ended inquiry methods (Gormally et al., 2011). Both open inquiry and guided inquiry methods commonly involve students working in groups to solve problems and do investigations.

Inquiry teaching methods also vary widely as to how they are implemented. Each scenario seems dependent on the course, number of students enrolled, facilities available and many other factors unique to each post secondary situation (Basey et al., 2000; Buck et al., 2008). Regardless of the type of inquiry being employed, Llewellyn’s Inquiry Cycle serves as a general format for inquiry based investigations (Llewellyn, 2005). The Inquiry Cycle involves six main phases; Inquisition, Acquisition, Supposition,

Implementation, Summation, and Exhibition. Inquisition involves students pondering a question or problem that they want to solve. This phase initiates the inquiry process. Acquisition follows where the students use their prior knowledge to brainstorm solutions to the problem. Supposition is the next stage and involves students developing a hypothesis to test the problem or question they are trying to solve. Implementation follows when students design experiments or develop a plan of action to test their predictions. The Summation stage involves students experimenting and recording and analyzing their data and observations to find conclusions. They determine whether their hypothesis can be supported by their experimentation. The Exhibition stage involves students communicating and justifying their results to others in a variety of methods. These could include methods such as written formal lab reports, open discussion forums, oral presentations, scientific posters, written journal articles, or Prezi and Power Point presentations to name a few. The Inquiry Cycle is a method of asking and addressing a question or problem. Students can enter and reenter the cycle at various stages throughout their investigation as their inquiry process continues (Llewellyn, 2005).

Llewellyn defines inquiry as a “scientific process of active exploration by which we use critical, logical and creative thinking skills to raise and engage in questions of personal interest” (Llewellyn, 2004, p. 24). Inquiry teaching strategies also use the 5E model developed from the Learning Cycle. The 5 E’s are Engagement, Exploration, Explanation, Elaboration and Evaluation. The 5E model is based on constructivism where learners use prior knowledge and experience along with exploration to build their own knowledge or learning of new ideas. The Biological Science Curriculum Study (BSCS) instructional model uses the 5E’s in inquiry methods of teaching. Educators use

students' prior knowledge and curiosity to engage them in new concepts in the Engagement stage. In the Exploration stage, students get hands-on experience performing activities that use prior knowledge to generate new ideas, explore questions and conduct investigations on a problem. In the Explanation stage, students focus on explaining their understanding of a concept. They communicate their understanding of a problem or concept that they have been investigating. In the Elaboration stage, educators have students expand and develop concepts they are investigating. Students are encouraged to develop deeper understanding of related concepts and acquire additional skills and information to conduct additional activities and learn more. The Evaluation stage enables the educator to evaluate the student's understanding and learning. Students can assess their understanding of concepts and teachers can revisit concepts and re-teach them if evidence of misconceptions is evident. In addition educators can also enhance students' learning by focusing on concepts that students have high interest levels in. This constructivist learning cycle is open-ended and allows educators be flexible to students learning needs (Bybee et al., 2006).

Because inquiry teaching in post secondary institutional settings is relatively new and because each teaching situation is unique to each institute, there isn't much information available on assessment tools for scientific inquiry. Some researchers propose developing scoring rubrics to grade inquiry activities and suggest using self-evaluation and peer evaluation of student inquiry projects (Lunsford & Melear, 2004). Other researchers are developing tools to assist educators in determining different levels of inquiry so that they can recognize and adjust inquiry levels better in their own teaching situations. Dolan and Grady have developed a matrix to allow teachers to reflect on

inquiry based teaching strategies so they can assess and plan inquiry in their own individual teaching situations. This Matrix for Assessing and Planning Scientific Inquiry (MAPSI) could be adapted for post secondary inquiry based laboratory and lecture courses to facilitate better understanding of the level of inquiry taught by instructors (Dolan & Grady, 2010; Grady, 2010).

While there are a few problems identified with implementing inquiry based learning into college/university level science laboratory and lecture courses such as student and instructor anxiety and frustration getting used to new ways of thinking (Huddleston & Addy, 2005), inquiry based learning has been shown to have positive effects on student learning (Lord & Orkwiszewski, 2006). Inquiry based learning helps students have deeper, long term understanding of science concepts and develop greater skills in scientific reasoning (Timmerman et al., 2008; Udovic et al., 2002). Inquiry based learning enhances students' attitudes towards science and promotes cooperative learning between individuals (Lord & Orkwiszewski, 2006). Inquiry based learning also helps students develop the "processes and skills used by scientists while carrying out investigations" (Basey et al., 2000, p. 80). Finally inquiry teaches "students to think as scientists" (Polacek & Levine Keeling, 2005, p. 52) and improves scientific literacy.

METHODOLOGY

The study group consisted of students registered in Biology 231, an introductory university transfer general biology course. Registration in Biology 231 consisted of

approximately 120 students in the fall term and 50 students in the winter term. Data was compiled from 151 students who completed the course. Others dropped the course at various stages throughout the term and their results were not included in this study. The majority of students registered in the course in the fall term were University Transfer (UT) Science students although a smaller number of students with diverse backgrounds from Arts, Business and Education were also enrolled. In the winter term, the majority of students were enrolled in the Nursing program although a small number were UT students including a couple of foreign students.

In this study I introduced the concept of inquiry based labs into the laboratory portion of Biology 231. One of the universities we have a transfer agreement with, University of Calgary (UofC), has been teaching inquiry based biology labs in their Biology 231 course for several years. In order to maintain some consistency with their science program, my aim was to introduce inquiry into the laboratory portion of the course so our program matched theirs more closely. Our transfer agreement doesn't require me to do so but I felt that our students would benefit when they transferred to their third year at UofC if they were taught using similar methods. My goals were to incorporate inquiry-based labs into the Biology 231 course in a stepwise fashion over several years converting the majority of the traditionally taught experiments to inquiry-based ones.

In this study year, two of the twelve labs were converted to inquiry based laboratory studies. The MHC Biology 231 lab manual was rewritten to include two new inquiry based labs, one on enzyme action, Inquiry Lab I – Enzymes (Appendix A) and one on microbiology, Inquiry Lab II – Isolation and Identification of an Unknown

Bacteria Isolated from Soil and Antibiotic Study (Appendix B). Both labs were included as inquiry treatment methods. In previous years the students did an enzyme analysis during the first lab of the course and the last six weeks of the course involved a study of microbiological techniques and general microbiology. For the treatment year the Biology 231 course was changed so that the first laboratory session of the course taught students basic techniques required to perform biological studies and enzyme assays. It was taught in a traditional non-inquiry manner. Students received basic safety instructions and were given information on experimental design and scientific formal laboratory report writing. They received instruction on principles of scientific method, Scientific Methods Lab (Appendix C). During the second week of the laboratory portion of the course students performed a basic enzyme experiment studying the effects of concentration of the enzyme catalase on the breakdown of hydrogen peroxide. Students followed a set of instructions using a traditionally taught cookbook type of laboratory procedure to perform the enzyme assay (Appendix A). They drew a standard curve of the enzyme activity and submitted the plot for evaluation and assessment before leaving the lab. This was to ensure that they understood basic principals of plotting graphs. They were taught x- and y-axes, how to label plots and how to interpret their data and results. Students were also instructed to form groups of four or five people for their upcoming inquiry experimentation project. They were allowed to choose their own study partners. They were given basic instructions on the goals of the inquiry based experiment. They were further instructed to do research on the enzyme catalase and design a project that would investigate the effect of any environmental factor on the enzyme catalase. They were told to exchange contact information with members of their groups (for example, phone

numbers, E-mail addresses) and were told they had to collaborate with their group members (out of laboratory time) to do research on the enzyme and design their experiment. Students had five days to submit an experimental design plan for their inquiry study of enzymes. Each student was required to submit his or her own experimental design even though the group had to meet, collaborate and decide on a common experimental design. Designs had to be submitted before coming to their first inquiry lab the following week to ensure that the necessary equipment, chemicals and supplies were available. Students received a grade for their submitted experimental design that was added to their formal report grade to determine their overall mark on inquiry enzyme study experiment. About forty percent of the students submitted experimental designs that were unacceptable for a variety of reasons. In some cases lab supplies weren't available and couldn't be ordered in time to conduct their experiments. For example one group wanted to test pressure effects on enzymes but pressure chambers weren't available for their use and students didn't have a clear idea of alternative methods of testing their hypothesis. High costs of materials and supplies were also limiting factors in some cases. Safety was a concern and in other cases, students' designs were too elementary for a university level course. Students whose designs were not acceptable were contacted by e-mail and meetings were arranged so I could outline my concerns about their projects. Students then came up with alternative design plans for approval before their scheduled laboratory time. The second and third week of the course involved the students' inquiry-based study of enzymes (Appendix A). Students had to modify their design plans, have them approved, perform their experiments and complete their experimentation in the two week period assigned to the laboratory experiment.

The overall purpose of the inquiry experiment was for students to examine the effects of any one environmental factor on catalase. Students were assessed on their prior knowledge and understanding of enzymes in a five question Enzyme Pre-Lab Quiz (Appendix D) before commencing the enzyme study and before their experimental design phase. Their learned knowledge was also assessed with a five question Enzyme Post-Lab Quiz (Appendix E) following completion of the enzyme inquiry lab and after they had written up and submitted a formal laboratory report on their experiment. The post-lab quiz questions were identical to the pre-lab questions. They were also evaluated on their understanding of enzyme theory in a series of questions on the midterm laboratory examination, Biology 231 Lab Exam 1, Treatment Question on Enzymes (Appendix F). In addition students were further assessed by receiving a grade on their enzyme experiment formal laboratory report, which was submitted one week after completion of their experiments. The formal laboratory report also included a mark for the experimental design which students had to have approved before being granted permission to conduct their experiments. A grading rubric for the enzyme laboratory experimental design, Experimental Design Grading Rubric – Inquiry Lab I & II (Appendix J) and for the formal laboratory report, Formal Report Grading Rubric - Enzymes (Appendix K) was used to evaluate students' work.

A non-treatment control laboratory was included in the study. The same students performed a Meiosis study in Lab 3 of the Biology 231 course using a traditional laboratory format. They used traditional non-inquiry methods to conduct a self-study unit where they examined a demonstration on meiosis in *Ascaris* sp. and answered questions in their lab manual on the stages of meiosis and fertilization in roundworms.

No pre or post lab questions were given to students in this experiment. Students were examined in a question on the first laboratory examination in which their knowledge on meiosis was assessed, Biology 231 Lab Exam 1, Non-treatment Question on Meiosis (Appendix G). Results of the same non-treatment (non-inquiry) control were compared with the treatment (inquiry) examination questions for both inquiry based experiments, Inquiry Experiment I and Inquiry Experiment II.

Inquiry Experiment II was conducted during the second half of the course. Students were taught techniques required to handle microorganisms safely before commencing the inquiry project. Laboratory instructions used traditional non-inquiry laboratory procedures to teach students how to streak plates, perform microbiological stains, maintain pure cultures and other basic microbiological techniques. During the last month of the course the students conducted an inquiry based study of microorganisms and antibiotics. They were required to isolate and identify an unknown organism (bacterial species) from soil using an identification key. In addition they had to design and carry out an antibiotic study of their own design with their isolated soil organism.

Students were assessed on their prior knowledge of antibiotics in a five question Antibiotic Pre-Lab Quiz (Appendix H) that was given to them before they had any theory on antibiotics in lecture or lab and prior to submitting their experimental design. Students worked in groups and submitted an experimental design of their proposed experiment prior to the lab by an assigned time. Students with experimental designs that were not acceptable were contacted by the instructor and alternatives were submitted before the scheduled laboratory period. Students were required to submit a formal laboratory report on their investigation one week after the inquiry lab was completed.

Their formal laboratory report included techniques used to isolate and identify their unknown organism. It also include their antibiotic study using the bacterial species they isolated and identified. A grading rubric for the antibiotic study experimental design, Experimental Design Grading Rubric – Inquiry Lab I & II (Appendix J) and for the formal report, Formal Report Grading Rubric – Antibiotics (Appendix L) was used to evaluate students' work. Students' learned knowledge of antibiotics was assessed in a post-treatment five question Antibiotic Post-Lab Quiz (Appendix I). The post-lab quiz was identical to the pre-lab quiz. Pre and post lab quiz marks were compared. Students were assessed through evaluation of an experimental design plan and evaluation of a formal laboratory report. In addition students were tested on their knowledge of antibiotics gained in a question on their final laboratory examination (Appendix M). The grade on the treatment examination question was compared to the grade they received on examination question from the non-treatment control laboratory on meiosis and fertilization in *Ascaris* sp. (Appendix G) in a previous laboratory examination.

In the antibiotic inquiry laboratory project students were given a soil sample, told to isolate and identify a bacterial species in it and directed to perform an antiobiotic study using the organism. The soil samples were composed of potting soil that was autoclaved in the lab and then inoculated with a known bacterial species. Known bacterial species were used for saftey reasons to ensure that students wouldn't isolate pathogenic organisms from untreated soil. Each group received a different unknown bacterial species. Students worked in groups of four or five. They were permitted to switch lab partners from their enzyme inquiry study groups if they chose. The majority of groups stayed with their initial partners and only two groups switched around members.

Microbiological samples were prepared by inoculating 0.5 grams of a prepared soil sample into 100 ml samples of sterile nutrient broth and incubated at 37°C for 24 hours by a technician. Students were allowed to choose their coded and numbered samples for experimentation. Students used isolation techniques to obtain pure cultures of their organism. They were informed that their unknown organism was a mesophilic bacterial species. Each student in the group used a multistreak technique to plate out their soil sample onto Brain Heart Infusion agar plates. Plates were incubated 37°C for 24 to 48 hours and then stored in a refrigerator until students could examine their plates for pure cultures. They then examined and recorded the cellular morphology of their organisms from Gram stains and spore stains. Students examined pure cultures of their organisms to record colonial morphology in order to identify the bacterial species. They also performed appropriate biochemical testing and used a Biology 231 identification key to identify their bacterial species. Once organisms were identified students were required to design and implement an antibiotic study on their bacterial species. If students did not identify their bacterial species properly they were not corrected. The project was an extensive multi-stepped experiment. After the identification steps were completed, students submitted experimental designs on an antibiotic study using their bacterial species. Designs were submitted one week prior to the experimentation lab to ensure that supplies and equipment were available. Students with unacceptable designs were contacted in advance and were requested to submit alternative or modified design plans. Students found the project challenging at first because it involved many steps. Students demonstrated a greater ability to think 'out of the box' on this inquiry project when compared to the first inquiry enzyme project. They didn't ask as many elementary

questions of the instructor and their inquiries seemed more complex and demonstrated a higher level of scientific method design involved in their experimentation. Some students designed very simple experiments involving antibiotic sensitivity testing of various antibiotics against their isolated organism using commercial antibiotic sensitivity discs placed on bacterial lawns. Other students had more complex intricate experiments involving minimum inhibitory concentration (MIC) testing of a variety of antibiotics against their organisms. Still other groups of students investigated production of antibiotics by their organism while some investigated both production and testing of antibiotics combined. Three groups of students investigated action of natural agents such as spices and substances like garlic and honey against their organisms. One student group investigated use of antibiotics in patients having high fevers and designed an experiment examining the effect of increasing temperatures on penicillin on their isolated organism.

Traditionally students in Biology 231 were assessed using weekly lab quizzes and two laboratory examinations. As a result they did no lab report writing in the course and their report writing skills were lacking when they advanced to second year biology courses. By implementing formal report writing into the course with the inquiry based laboratory examinations, I hoped to improve my students' lab report writing skills and knowledge of basic scientific experimentation skills. Students had to write two formal reports as a result, one for the enzyme lab and one for the microbiology antibiotic study.

Before the study, Biology 231 students were assessed using a midterm laboratory examination (on the first six labs) and a final laboratory examination (on the last six labs). Both exams were timed examinations where students were assessed using a variety

of practical and theoretical questions. The assessments remained the same in the newly revised course. Students still had two lab exams, identical to those given for the past ten years. Data of pre-treatment quizzes and post-treatment quizzes were compared to test the effects of the inquiry based labs in the course. Results on examination questions from both treatment inquiry based labs were compared to an examination question from the non-treatment control lab taught using traditional non-inquiry methods to examine the effects of inquiry and non-inquiry laboratories on student comprehension of biological principles studied. The same students were given both midterm and final laboratory examinations.

The following table outlines the Biology 231 experiments that served as the inquiry treatment labs as well as the non-treatment non-inquiry control experiment used in this research project.

Table 1
Outline of Treatment vs Non-Treatment Control Laboratories in Biology 231

Laboratory:	Inquiry Lab I (Non-traditional instruction)	Inquiry Lab II (Non-traditional instruction)	Non-Inquiry Lab (Traditional lab instruction methods)
Subject:	Enzyme Analysis	Microbiological Study	Meiosis Lab
Topics studied:	Factors affecting catalase activity	Isolation and identification of bacterial species from soil Antibiotic study using bacterial species isolated and identified	Demonstration laboratory taught in traditional manner on stages of meiosis in <i>Ascaris</i> sp.
Type of learning:	Inquiry – students design and implement experiment	Inquiry – students design and implement experiments	Didactic instruction – students examine demonstration and record results and memorize facts

Assessment methods:	Pre-lab quiz Experimental design Formal laboratory report Post-lab quiz Laboratory examination question	Pre-lab quiz Experimental design Formal laboratory report Post-lab quiz Laboratory examination question	Laboratory manual questions to complete (voluntary, no marks assigned) Laboratory examination question
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The following matrix indicates the data collection methods that were used to substantiate the research project.

Table 2
Data Collection Methods

Factor	Data Source 1	Data Source 2	Data Source 3
Pre-existing knowledge	Evaluation of pre-lab quiz on Enzymes Evaluation of pre-lab quiz on Antibiotics	Examination of experimental design plans	Instructor observation
Inquiry Lab I & II (Some guided inquiry as required by students)	Instructor observation	Evaluation of experimental designs (Inquiry Lab I & II)	Evaluation of formal reports (Inquiry Lab I & II)
Overall effectiveness of inquiry based labs	Evaluation of midterm lab exam question on enzymes (treatment lab) and on meiosis (non treatment lab – Control)	Evaluation of final lab exam question on antibiotics (treatment lab) and on meiosis (non treatment lab – Control) Comparison of data on antibiotic exam	Evaluation of post-treatment quiz questions on Enzymes and Antibiotics

		question (Inquiry treatment) with identical exam question from terms prior to introduction of inquiry research (control – non-treatment)	
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In order to examine the effects of incorporating inquiry based labs into the course to determine their effect on student learning, a series of statistical analyses were employed to analyze students' performance on examinations for both the enzyme questions and for the antibiotic sensitivity and resistance questions. Standard deviations and averages were calculated for each analysis method. Pre and post treatment quiz questions were compared to see if students' understanding of biological principals under examination changed over the course of both inquiry laboratory projects and writing up their formal reports. Laboratory report grades were examined independently for each inquiry project. Student marks from examination questions of treatment inquiry experiments were then individually compared to marks from the student examination question on the control, a non-treatment, non-inquiry experiment.

Past data from an antibiotic examination question given in a previous year before inquiry was introduced to the course was compared to the antibiotic examination question given to students after inquiry was introduced to the course to see how inquiry impacted student knowledge of antibiotics.

In addition I noticed that my students didn't demonstrate much lasting knowledge of general biological principles once they passed Biology 231 and moved on to advanced biology courses. Part of the reason for this is that both Biology 231 lectures and

laboratory experiments had been taught for the past ten years in a non-inquiry traditional manner. Second year students in MHC's Cellular and Molecular Microbiology course (CMMB 343) showed very little recall of biological principles or microbiological techniques that they learned in their prerequisite Biology 231 course the previous year. Consequently my aim was to improve their long-term understanding of biology using inquiry based learning techniques.

In addition, students in MHC's University Transfer Science program receive very little practice in writing scientific formal reports in biology and chemistry courses in their first year. Another of my aims was to introduce formal laboratory report writing into the Biology 231 course to give students an opportunity to write formal scientific reports to better prepare them for scientific research papers and projects that they encounter in higher level Science Department courses in third and fourth year programs at transfer institutes.

Formal laboratory report writing abilities were analyzed by comparing the students' second formal reports (Inquiry Lab II) to the students' first formal reports (Inquiry Lab I) to see if their report writing skill improved.

DATA AND ANALYSIS

The study investigated the effects of two inquiry experiments on students' comprehension of biological topics being studied in Biology 231. Data were obtained from the enzyme Inquiry I experiment during the winter term of 2012. Data were obtained and pooled together from the Antibiotic Soil Inquiry II experiment in both the fall 2011 term and the winter 2012 term.

The first of the inquiry experiments implemented was a study of enzymes. Forty students ($N=40$) registered in the winter 2012 term were surveyed for the enzyme inquiry study. Data from a five question pre-treatment laboratory quiz on enzymes taken in the students' first laboratory session, prior to receiving any background information on enzymes in either lecture or labs were compared to an identical five question post-treatment laboratory quiz on enzymes taken after students had designed and implemented their enzyme experiments and submitted formal laboratory reports. The use of pre and post laboratory enzyme quizzes were compared to identify differences in student comprehension of enzyme theory as a result of students' designing and implementing their own enzyme experiment. Data showed that sixty seven and a half percent of students demonstrated an increase in conceptual knowledge of enzymes after performing their inquiry experiment. This was evidenced by the difference in percentage in the score on their post-lab quiz when compared to the pre-lab quiz score. Fifteen percent of the students showed no change in grade and seventeen and a half percent of the students showed a decrease in their quiz score (Figure 1).

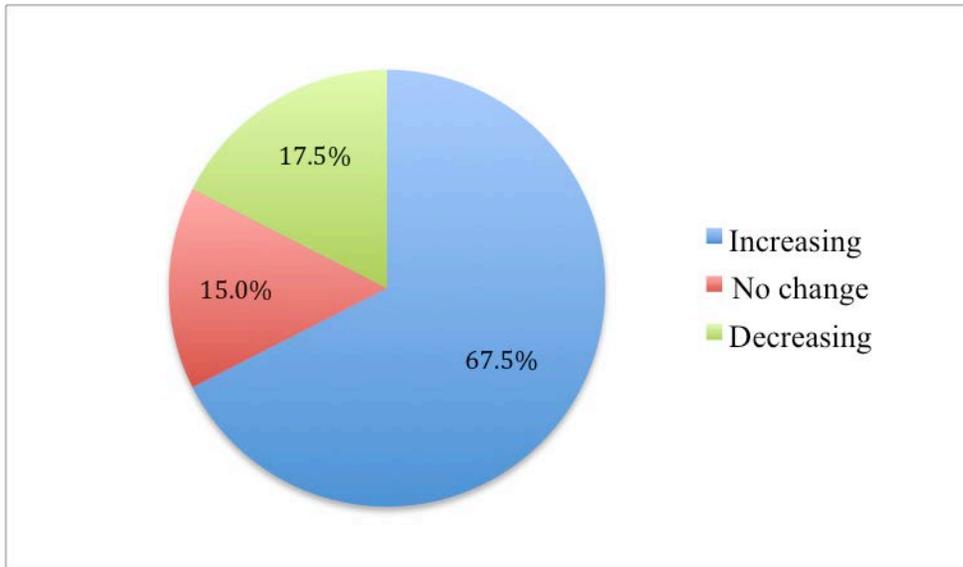


Figure 1. Percentage of students showing change in conceptual knowledge following inquiry experiment on enzymes, ($N=40$).

Pre-lab quiz scores were compared to post-lab quiz scores and the percent difference in scores were calculated. Of the twenty six students showing increasing knowledge of enzyme theory following the treatment method, eight scored between zero and up to ten percent higher on the post lab quiz when compared to the pre lab quiz. Nine students showed an increase of between ten up to twenty percent, six showed an increase of between twenty up to thirty percent and four showed between a thirty and a forty percent increase in enzyme knowledge following the enzyme inquiry laboratory as evidenced by their increased score on the post lab quiz. No students had increases over forty percent. The frequency of students showing an increase in their knowledge of enzyme theory is shown in Figure 2.

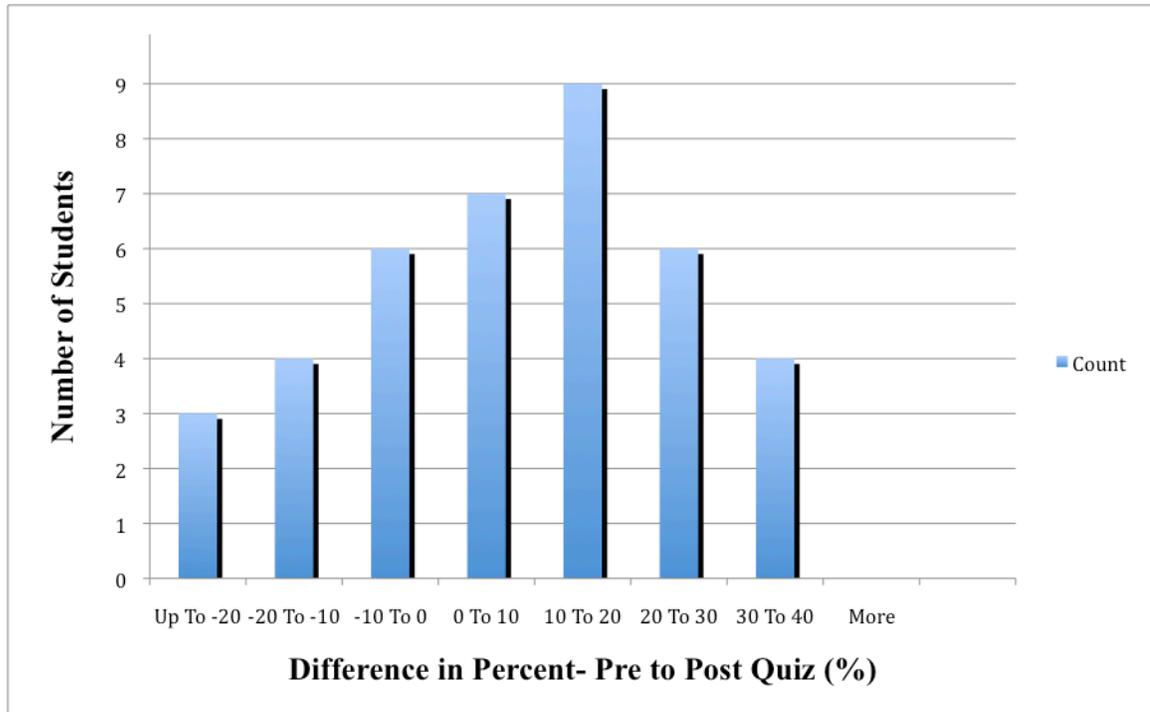


Figure 2. Frequency of students showing increases in conceptual knowledge of enzymes following treatment unit, ($N=40$).

Students submitted formal laboratory reports on their proposed experiments. The average grade on the formal lab report was seventy nine percent with a standard deviation of ten. The average student grade on the enzyme question on the laboratory examination was seventy eight percent with a standard deviation of ten. These levels of comprehension of enzyme knowledge are similar.

An examination of data from a control non-treatment non-inquiry examination question showed that the students had an average of twenty six percent with a standard deviation of twenty three on the question. This indicates a low level of comprehension of meiosis, a topic that was studied using non-inquiry methods in Biology 231. The overall average grade on the laboratory examination was sixty two percent with a standard deviation of twelve. A comparison of the average treatment exam question grade,

average non-treatment exam question grade and average overall laboratory examination grade is shown in Figure 3.

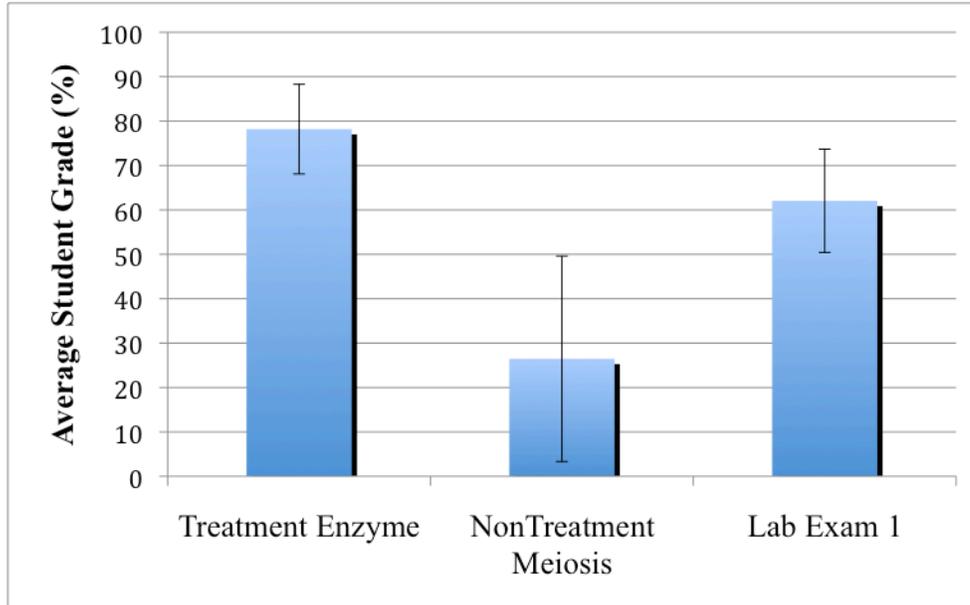


Figure 3. Comparison of average student grades on treatment and non-treatment examination questions and overall lab examination scores with accompanying standard deviations, ($N=40$).

Ninety eight percent of the students showed a higher grade on the treatment inquiry enzyme examination question than on their midterm examination grade and than the control non-inquiry question. This indicates that their knowledge of the enzyme topic was greater than their overall understanding of topics covered in the non-treatment experiment questions on the examination. Based on my experience teaching the same laboratory course over the past ten years using similar examination questions, I feel that the students showed improved knowledge of enzymes as a result of the inquiry based laboratory than in past years when taught using traditional non-inquiry methods. Similarly, students have consistently showed low comprehension of meiosis on the

control non-inquiry lab examination meiosis question for the past ten years and did so again this year.

The second of the inquiry experiments was a microbiological study. Seventy one students registered in Bio 231 in the fall 2011 term and forty students registered in the winter 2012 term were surveyed for the antibiotic inquiry study for a total of one hundred and eleven students ($N=111$). Data from a five question pre-treatment laboratory quiz on antibiotic theory taken in a laboratory session, prior to students receiving any information on antibiotics in either lecture or labs were compared to an identical five question post-treatment laboratory quiz taken after students had designed and implemented their inquiry experiments and submitted formal reports. The use of pre and post laboratory antibiotic quizzes were compared to examine differences in student comprehension of antibiotic theory as a result of students' designing and implementing their own inquiry experiment. Data showed that ninety five percent of students demonstrated an increase in conceptual knowledge of antibiotics after performing their inquiry experiment. This was evidenced as the difference in percentage in the score on their post-lab quiz when compared to the pre-lab quiz score. Five percent of the students showed no change in grade and none of the students showed a decrease in their quiz score after completing the treatment exercise (Figure 4).

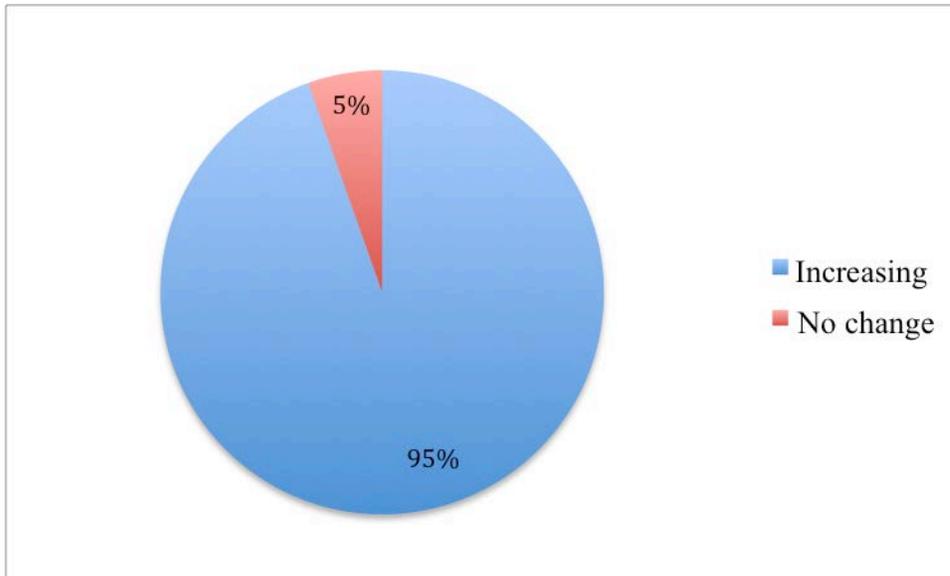


Figure 4. Percentage of students showing change in conceptual knowledge following inquiry experiment on antibiotics, ($N=111$).

Pre-lab quiz scores were compared to post-lab quiz scores and the percent difference in scores were calculated. Of the ninety five percent of students ($N=106$) showing increasing knowledge of antibiotic theory following the treatment method, twenty students scored up to ten percent higher on the post lab quiz when compared to the pre lab quiz and fifteen students showed between a ten up to twenty percent increase in quiz scores. Twenty three students showed an increase of between twenty up to thirty percent, eighteen showed between thirty up to a forty percent increase, and twelve showed an increase in scores of between forty to fifty percent. Eight showed increases of scores of between fifty up to sixty percent increase and four of the students showed increases of between sixty up to seventy percent. An additional four students showed increases of between seventy to eighty percent in scores indicating an increase of antibiotic knowledge following the antibiotic inquiry laboratory. The frequency of students showing an increase in their knowledge of antibiotic theory is shown in Figure 5.

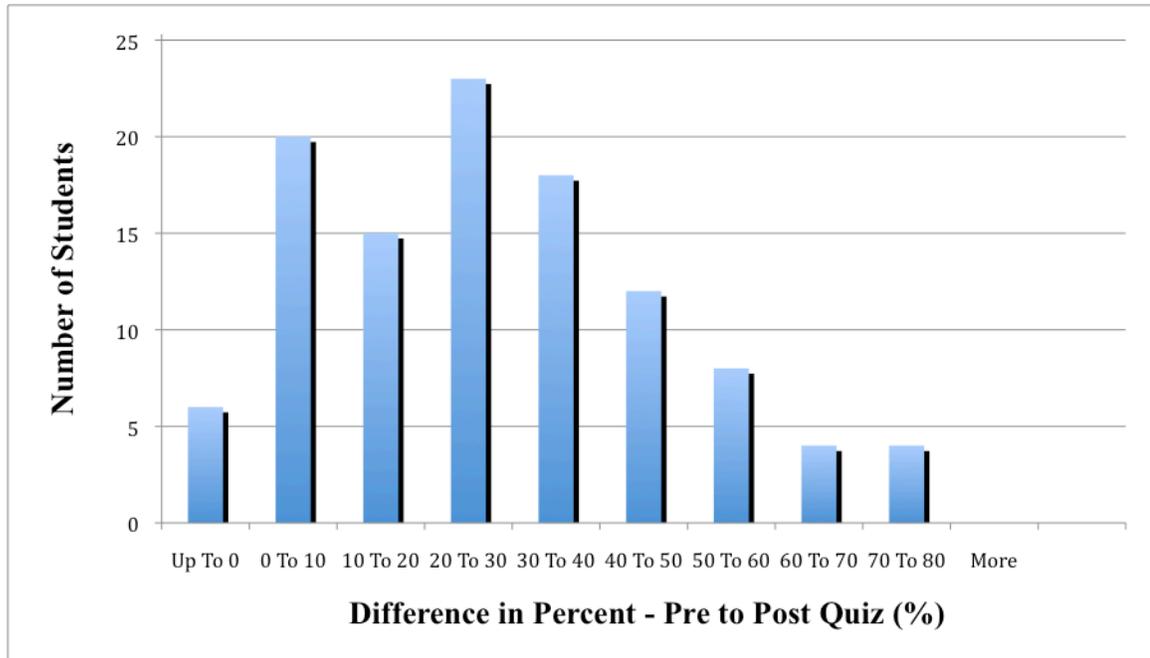


Figure 5. Frequency of students showing increases in conceptual knowledge of antibiotics following treatment unit, ($N=111$).

Students submitted formal laboratory reports on their experiments. The average grade on the formal lab report was seventy six percent with a standard deviation of thirteen. The average grade on the first inquiry formal lab report on enzymes was seventy nine percent with a standard deviation of ten, closely paralleling that of the second inquiry formal report on antibiotics. The average student grade on the antibiotic question on the laboratory examination was slightly lower, sixty eight percent with a standard deviation of twenty two.

An examination of data on the control non-treatment non-inquiry meiosis examination question showed that the students had an average score of thirty percent with a standard deviation of twenty four on the question. This indicates a low level of comprehension of a topic that was studied using non-inquiry methods in Biology 231. The overall average grade on the laboratory examination containing the antibiotic

question was sixty five percent with a standard deviation of fourteen. A comparison of the average treatment exam question grade, average non-treatment exam question grade and average overall laboratory examination grade is shown in Figure 6.

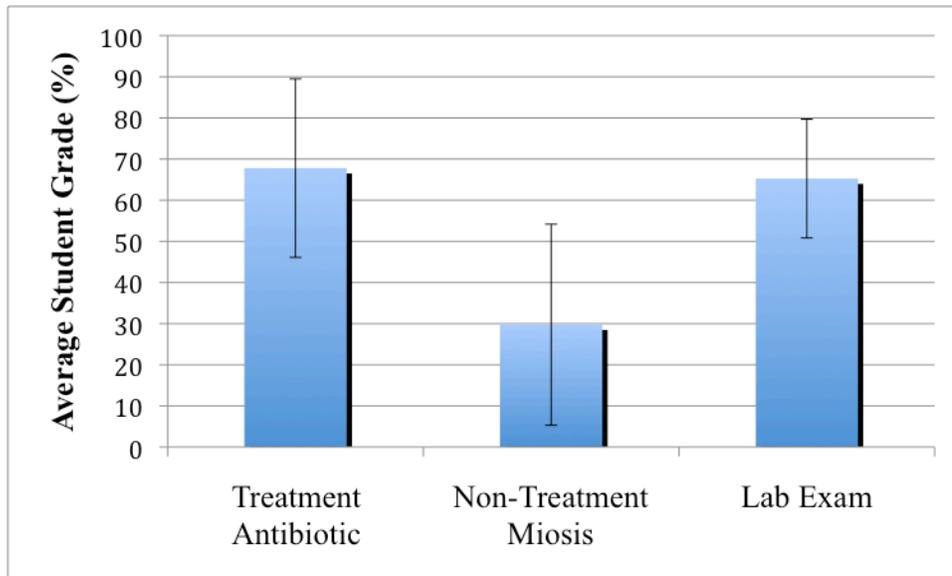


Figure 6. Comparison of average student grades on treatment and non-treatment examination questions and overall lab examination scores with accompanying standard deviations, ($N=111$).

My experience teaching microbiology labs over thirty years leads me to believe that the inquiry based microbiology project helped the students score higher on the treatment antibiotic question than in the past ten years of giving the same question on the final laboratory examination. Data from an identical antibiotic question given on a Biology 231 laboratory examination during the fall 2010 term and winter 2011 term

(prior to inquiry being introduced into Biology 231) was compared to the research project data from the study terms. Data is outlined in Table 3.

Table 3

Comparison of Antibiotic Examination Question Data: Traditional Non-Inquiry Antibiotic Experiment vs Inquiry Antibiotic Experiment

Term	Type of Experimental Instruction	Number of Students (N)	Average Score on Examination Question (%)	Standard Deviation
Winter 2010	Traditional non-inquiry experiment pre-research project (control)	32	54.5	33.7
Fall 2010	Traditional non-inquiry experiment pre-research project (control)	71	59.5	36.3
Fall 2011	Inquiry experiment-research project (test)	71	68.0	22.0
Winter 2012	Inquiry experiment research project (test)	40	67.0	22.0

Pre and post inquiry data were compared. The average on the antibiotic question following the inquiry labs was 68% with a standard deviation of 22 during the fall 2011 term and similar average of 67% with a standard deviation of 22 during the winter 2012. This is higher when compared with the previous years antiobiotic non-treatment, non-inquiry laboratory. Students taught in a traditional cook-book non-inquiry style during the winter 2010 term scored an average of 54.5 % with a standard deviation of 36.3 on the identical antibiotic exam question. The fall 2010 students had an average of 54.5 % with a standard deviation of 33.7 on the same antiobiotic question. Students taught the

lab using inquiry techniques had higher average score during the fall 2011 and winter 2012. Students taught prior to this time using non-inquiry traditional methods scored lower on antibiotic subject matter.

INTERPRETATION AND CONCLUSION

The purpose of this research project was to introduce inquiry based laboratory experimentation to a biology course and determine its impact on student learning inquiry based labs. Students showed gains in overall knowledge in the subject areas under investigation following the inquiry based laboratories when compared to learning in traditional non-inquiry laboratories.

My experience teaching students over the past thirty years at the post secondary level indicates that students had better learning of subject matter after being doing inquiry projects in the laboratory. I feel that the gains in scores on post-inquiry lab quizzes when compared to pre-inquiry lab quiz scores indicated that inquiry based learning improves students' learning of basic biological concepts based on my prior teaching experience. It is also my feeling that inquiry based learning helped the students' obtain higher scores on laboratory examination questions on inquiry based topics than I've seen in the past when students were taught using non-inquiry methods. Scores on examination questions from each of the inquiry treatment units were higher for most students when compared with scores on examination questions for the control laboratory examination question.

I also noticed that students became became more interested in the topics they were investigating with inquiry projects and became active members in their own

learning. They were forced to discover knowledge on their own and the two projects provided them with the opportunity to do so. Students spent more time studying and designing their experiments and as a result learned more about enzymes and antibiotics than they did in past years when they were taught using traditional non-inquiry methods.

In the inquiry projects students were given the freedom to investigate any factor they choose provided I could supply them with the supplies they needed. I was encouraged when students submitted a wide variety of experimental designs on the enzyme project. Experimental topics included effects of temperature on enzymes, metal ion effects on catalase, pH effects on catalase, effects of osmotic pressure on catalase, effects of sugar on catalase to name a few. Students were encouraged to work together in their groups to research and design an experiment. A couple of students that had trouble finding people to work with were assisted in being assigned to a group. Some students really enjoyed the freedom of the project and enjoyed working in groups. They enjoyed the social aspect of collaborating in a group and being able to meet for coffee in the library or off campus to work on their project. Students only had four to five days to submit experimental designs so they were forced to work hard doing research on their projects in a short time period. Some groups divided up the work amongst themselves. Other students had a lot of trouble thinking 'out of the box' and initially had trouble brainstorming and thinking of topics. The majority of students worked well in their groups but some found the exercise to be frustrating, time consuming and difficult.

In most cases I encouraged students to find answers to their own questions and encouraged inquiry learning by not answering student questions unless they could not find answers on their own. Most students did do their own research to answer their own

questions once they discovered that I wasn't going to provide an easy answer to their question directly and when they realized that I was encouraging them to work out their own problems. I did offer assistance to students lacking basic scientific knowledge or skills required to perform experiments but this was a rare occurrence. I found it difficult to not jump in and try to answer students' questions as soon as they asked them. I was taught in a traditional passive learning manner and it was a valuable learning experience for me to have to encourage my students to investigate a problem and not offer them immediate solutions. In most cases I had to 'bite my tongue' and mentally force myself to assist and guide their inquiry rather than to offer an immediate solution. Other laboratory instructors involved in the course indicated that they had trouble doing this as well. In fact I had some concerns towards the end of my research project that the lecture professor in the course was answering student inquiry questions on antibiotics and I had to ask him to not offer advice and solutions to the students but rather encourage them to do some research on their own problems. Since he was also teaching a laboratory section of the course and performing my inquiry experiments he understood my concerns and assisted me in encouraging students to do their own research.

The increase in student comprehension of enzymes and the high scores on the enzyme question on the first laboratory examination indicate that the majority of students benefitted from searching out answers to their own questions. They showed much improved knowledge of enzyme content than I had seen over the past ten years of having similar questions on enzymes on Biology 231 lab exams.

In comparison, students did very poorly on the control non-treatment meiosis question on the first laboratory examination. This lab was a demonstration laboratory

where students assumed a passive learning role. Students were given an experimental protocol with a large amount of knowledge on the stages of meiosis to examine and memorize. Students didn't receive any assessment on this laboratory before or after they performed it other than the question that appeared on their laboratory examination. Many students just breezed through the six microscope demonstration stations in less than five minutes without even asking any question of me. The majority of students didn't take any sketches or record any notes of what they observed in the demonstration. They worked on their own or in pairs if they choose. They didn't have any opportunity to question what they were learning and weren't given a reason to communicate their ideas or knowledge gained on the meiosis project with anyone. They were responsible for their own learning but weren't required to submit any drawings or lab report on the material being examined. They answered several questions in their laboratory manual but these weren't evaluated. The low scores they obtained on this question indicated that the weren't engaged in the topic and the majority of students weren't successful with gaining much conceptual knowledge of the topic as a result.

My experience teaching leads me to believe that inquiry experimentation resulted in enhanced conceptual knowledge of antibiotics for the majority of students in Biology 231 when compared to results from past years. Examination questions on the laboratory examinations were answered in more depth and with deeper scientific knowledge than in the past. Students showed better understanding of variables and controls used in scientific method when doing their formal laboratory reports after performing inquiry based projects than in the past. They also developed better experimental hypotheses and improved methods of proving or disproving their hypothesis. Several students were

disappointed to find that their experimental results didn't support their hypothesis. It was a learning experience for them to realize that not all experiments are successful and that disproving a hypothesis is actually a valid and useful scientific result.

I used a combination of inquiry methods in my research project. My goal was to give my students some guidance in basic experimental technique and provide them with basic skills in experimentation before letting them loose in the laboratory. I also provided students with some guidance if they were really struggling with basic laboratory skills or didn't have the scientific background to answer basic scientific method questions. In general students were given the freedom to perform their own experiments in the manner in which they wanted to perform them. I noticed that students interacted in groups in and out of class to share their knowledge and to question each other's thinking and knowledge as the laboratory course progressed. Their thinking and communication skills improved over time.

In summary inquiry learning encouraged my students to be actively involved in my laboratory course and resulted in improved knowledge of the biological principles being investigated.

VALUE

My research supports the growing trend in education towards the implementation of inquiry based education. It showed me that students develop a deeper understanding and knowledge of a subject if they are responsible for their own learning. They invest in the learning and are committed to learning if they use inquiry methods. Students developed a sense of accomplishment in their learning when they chose a problem to investigate, chose their own tools and methods to investigate their problem and solved the problem on their own. Even proving that there wasn't a solution to their problem was a valuable experience for them.

I will use more inquiry methods in my laboratory courses in the future. My future plans are to switch all the laboratory exercises in Bio 231 from non-inquiry to inquiry based experiments, involving more multi-step experiments rather than one topic, one step labs taught in a traditional non-inquiry method.

I found inquiry teaching to be very time consuming and challenging as an instructor. I found myself being mentally challenged often when students had ideas on topics I hadn't considered and I had to do research on their topics when I was reviewing their experimental designs. I learned in the process and my project assisted in giving me new challenges and breathed new life into me as a teacher. I had to be 'on my toes' in the labs because students were thinking of new projects and ideas. It was stimulating and exciting to be in the laboratory when students were brainstorming. One problem is that the assessment of inquiry learning was a very time consuming process. It took me twenty to thirty minutes to grade each formal laboratory report even though I had designed a

grading rubric. Two other laboratory instructors found the assessment process very laborious. One lab instructor involved in the fall term was quite upset because she found the process so time consuming when compared to previous assessment techniques of a ten question multiple choice given weekly that was graded using a Scantron machine.

The improvement in learning that my students demonstrated in my inquiry laboratories more than made up for the inconveniences I experienced during my first experience with inquiry teaching. My job as a college laboratory instructor is to assist students develop as much understanding as they can and I now know that inquiry methods are the manner in which students can do that. My research has made me excited about teaching again and my enthusiasm will be transferred to my students as a result. I am currently designing a new Microbiology course to teach to students in the Nursing Program at Medicine Hat College in the Winter 2013 and I plan on incorporating inquiry based methods in my lectures and laboratories as a result of my capstone project research.

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APPENDICES

APPENDIX A

INQUIRY LAB I - ENZYMES

Biology 231 Laboratory Manual

LAB 2 - Enzymes

Suggested Readings: Raven, Chapters 3 and 6

Objectives:

1. *To be able to formulate and apply a hypothesis to each set of enzyme experiments.*
2. *To be able to apply principles of scientific method to each set of experiments.*
3. *To examine the effects of enzyme concentration, pH, and temperature on enzyme activity.*

Introduction:

Biochemical reactions in living cells are responsible for many metabolic functions, such as energy generation, protein synthesis and detoxification of harmful substances. Almost all biochemical reactions are mediated by enzymes. Some of these biochemical reactions would occur in the absence of enzymes, but at rates too slow for metabolic functions and activities that are required for life. Therefore questions regarding factors that effect enzyme activity, or its ability to carry out chemical reactions, are fundamental to science of life; biology.

Enzymes are defined as a protein serving as a catalyst, a chemical agent that changes the rate of a reaction without being consumed by the reaction. While most enzymes are proteins however there are ribozymes – RNA molecules that act as catalysts. While enzymes cannot change the equilibrium of a reaction, they do affect the rate of a reaction. Enzymes increase the rate of a reaction by lowering the activation energy of the reaction.

Enzymes are proteins composed of complex three-dimensional structures consisting of one or more polypeptide chains folded to form an active site. For an enzyme reaction to occur, the **enzyme** active site binds with a specific reactant molecule, called a **substrate** to form an **enzyme-substrate complex**. In this form the enzyme converts the substrate molecules to the **products** of the reaction. When the product is formed, the enzyme is then released and is free to combine again with more of the substrate molecules.

Enzyme + Substrate \rightleftharpoons Enzyme-Substrate Complex \rightleftharpoons Enzyme + Products

Enzymes are very specific in their action and will only catalyze reactions with certain types of molecules. Some enzymes act only on proteins and are called proteases. Others act on carbohydrates and are called carbohydrases, and some act only on lipids and are called lipases.

Enzymes, and their ability increase reactions rates, are affected by changes in temperature, alterations in pH, interactions with certain ions, and contact with inhibitors. The

rate of an enzymatic reaction can also be affected by the relative concentrations of the enzyme and substrate in the reaction mixture.

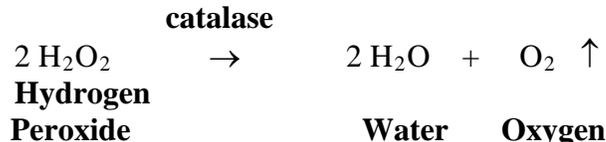
In this experiment you will investigate how changes in pH, temperature, and enzyme concentration will affect the enzymatic activity of the enzyme catalase.

This is a two-part experiment. In this lab you will measure the enzyme activity of catalase and develop a standard curve to quantify your data. Then you will design an experiment to determine the effect of an environmental factor on enzyme activity of catalase.

The Enzymatic Activity of Catalase:

Catalase is a very important enzyme for the detoxification of **hydrogen peroxide**, a potentially harmful molecule, which is a result of some chemical reactions in all cells. Hydrogen peroxide can damage cell components or can be converted to the highly reactive hydroxyl radical which attacks fatty acids, resulting in lipid peroxidation, loss of membrane integrity, and ultimately cell death. Since hydrogen peroxide is highly toxic, it is often used as an antiseptic to kill bacteria and other organisms in open wounds.

Catalase is an enzyme that breaks down hydrogen peroxide spontaneously to the harmless products of water and oxygen. The equation of this reaction is:



In order to investigate the rate of this chemical reaction we can either measure the consumption of the substrate or the accumulation of the products. There is no reason to measure the catalase concentration, since it is an enzyme and therefore not consumed in this reaction. Both hydrogen peroxide (substrate) and water (product) are colorless and difficult to detect visually. Fortunately, the oxygen (product) will bubble out of solution and is relatively easy to measure visually.

Consequently, you will measure the rate of this reaction by the rate of oxygen generation. You will soak filter paper discs in the enzyme catalase. Then you will drop the catalase soaked discs into vials of hydrogen peroxide. As the catalase enzyme catalyzes the breakdown of hydrogen peroxide into water and oxygen, oxygen bubbles will form and adhere to the surface of the disc. The accumulation of bubbles on disc causes it to float to the surface of the solution. Our working assumption is that the faster the disc floats to the surface of the solution, the faster the reaction rate.

PART I - WEEK 1. Experiment 2-1: The Effect of Enzyme Concentration on the Enzyme Activity of Catalase – Preparation of a Standard Curve

Theory:

In any biological reaction, the enzyme activity is affected by the concentration of the enzyme relative to its substrate. If there are many more substrate molecules than enzyme molecules in the reaction then the reaction rate is low since it takes the few enzyme molecules longer to convert the higher number of substrate molecules to product. In this situation, increasing the concentration of enzyme increases the overall reaction rate since there are now more enzyme molecules to react with the same number of substrate molecules. The rate is usually directly proportional to the enzyme concentration. However, there is a limit to increasing a reaction rate with an increasing enzyme concentration. At some point all the substrate molecules will be engaged with enzyme molecules and adding more enzyme will not increase the reaction rate any further. In addition, the reaction rate will increase in proportion to an increasing enzyme concentration only if the substrate is present in excess amounts, so that the reaction is not limited by the availability of the substrate.

In this experiment you will prepare different concentrations of the enzyme catalase. You will then investigate how different concentrations of catalase affect the rate of hydrogen peroxide breakdown.

Materials:

100 % Catalase Solution
 Distilled Water
 Hydrogen Peroxide – pH 7
 Hydrogen Peroxide (pH adjusted) for Experiment 1-3 (pH 2, pH 4, pH 7, pH 9, pH 11)
 Graduated cylinder – 10 ml
 Beakers – 50 ml
 Glass vials
 Filter paper discs
 Forceps, stopwatch, ruler, masking tape, marking pens
 Water Baths set at various temperatures for Experiment 1-2

Procedure: (Work in groups) Preparation of a Standard Curve

1. A stock solution of 100 % catalase has been prepared for you. Prepare different concentrations of catalase using the 50 ml beakers provided. You will need to dilute the stock solution of catalase a number of times to prepare solutions with different concentrations of the catalase. Label your beakers with the concentration of catalase solution.

Final Quantity Desired	Amount Catalase (ml)	Amount Water (ml)	Concentration of Final Catalase Solution
10 ml	0	10.0	0 %

10 ml	1.0	9.0	10 %
10 ml	2.0	8.0	20 %
10 ml	3.0	7.0	30 %
10 ml	4.0	6.0	40 %
10 ml	5.0	5.0	50 %
10 ml	6.0	4.0	60 %
10 ml	7.0	3.0	70 %
10 ml	8.0	2.0	80 %
10 ml	9.0	1.0	90 %
10 ml	10.0	0.0	100%

- Fill a clean glass vial with hydrogen peroxide (substrate) solution at pH 7 to the line indicated by your instructor. Measure the height of the hydrogen peroxide in the vial in mm. Draw your own data table and record you're the height of hydrogen peroxide on your table.
- Using forceps pick up a filter paper disc, holding it as close to the edge of the disc as possible. Submerge the disc into the 0% catalase (enzyme) solution for 5 seconds while continuing to hold it with the forceps. Do not drop the disc into the catalase solution.
- Remove the disc from the catalase solution.
- Drop the disc into the hydrogen peroxide by gently touching the disc to the surface of hydrogen peroxide then releasing the forceps. This technique should prevent the disc from sticking to the side of the glass vial.
- Immediately start timing with a stopwatch.** Stop timing when the disc rises to the surface and record your result. If the disc has not risen within two minutes, write 'no reaction' on your data table. If the disc rises within two minutes, record the time and distance traveled in your table as Trial 1. Repeat the test two more times and record the data as Trial 1 Trial 2 and Trial 3.
- Calculate the rate of reaction (mm/sec) for each trial and enter the data in your data table. Repeat steps 2-8 for the remaining catalase solutions for a total of three replications at each catalase concentration.

ACTIVITY: (Each student)

- Using the graph paper provided, draw your standard curve of enzyme.

instructor by the end of today's lab period so that the instructor can evaluate the feasibility of your proposal. Include each student's name on the proposal and each student's e-mail address. Your instructor will reply to your proposal to indicate its suitability for experimentation next week.

Each student should record your group's design proposal in your lab notebook so that you can prepare data tables for next week's lab and so that you can write up the formal lab report for this experiment and turn it in for the lab deadline. Your instructor will notify you when the formal report is due. You will also need this information for studying for laboratory examinations.

EXPERIMENTAL DESIGN QUESTIONS TO CONSIDER IN DESIGNING YOUR EXPERIMENT:

(Your group should be able to answer these questions before submitting your design to your instructor)

1. What problem/question are you investigating?
2. Based on information from your group, what is the **hypothesis** for the experiment you are designing?
3. What is the independent variable in your experiment?
4. What is the dependent variable in your experiment?
5. What is/are the controls? What is a control? Why should your experiment have controls?
6. What variables are you maintaining constant in your experiment? Why should these variables be kept constant?
7. Do you have replicates for each treatment? Why or why not?
8. What is your step-by-step procedure for your experiment? How long will your procedure take?
What special equipment/chemicals/materials will you require? Your procedure should be detailed enough so that other trained people could follow it.
9. How will you record your data and present it? (e.g. What will your data tables look like, how will you draw plots, e.g. line graphs, bar graphs. Can you use statistics to present your data?)

APPENDIX B

INQUIRY LAB II – ISOLATION AND IDENTIFICATION OF AN UNKNOWN
BACTERIA ISOLATED FROM SOIL AND ANTIBIOTIC STUDY

Biology 231 Laboratory Manual

LAB 10 – Inquiry Study - Antibiotics

Objectives:

1. *To isolate organisms in pure culture from a natural mixed specimen of microorganisms in soil.*
2. *To identify an organism isolated using biochemical tests, colonial and cellular morphology.*
3. *To determine whether the organism produces and/or is affected by antibiotics.*
4. *To determine what makes an effective antimicrobial agent.*

Chemicals like antibiotics, antiseptics and disinfectants have been used historically for a long time:

“It was during a visit through Central Europe in 1908 that I came across the fact that almost every farmhouse followed the practice of keeping a moldy loaf on one of the beams in the kitchen. When asked the reason for this I was told that this was an old custom and that when any member of the family received an injury such as a cut or bruise, a thin slice from the outside of the loaf was cut off, mixed into a paste with water and applied to the wound with a bandage. I was assured that no infection would then result from such a cut”. Dr. A.E. Cliffe, Montreal biochemist (<http://ntweb.deltastate.edu/jtift/scbm/scbm-2.html> - A Selected Chronological Bibliography of Biology and Medicine — Part II)

Antibiotics weren't recognized as therapeutic agents until Alexander Fleming's discovery of penicillin produced by the fungus *Penicillium notatum* in the 1930's. Antibiotics are natural antimicrobial agents produced and secreted by bacteria, fungi and actinomycetes. These chemicals inhibit the growth of some pathogenic microorganisms by destroying or altering one or more of their essential metabolic pathways. Today many agents used to treat microbial growth are produced synthetically but the term **antimicrobial** is applied to all chemicals used for this purpose.

This lab involves an inquiry study. You will work in small groups to form a hypothesis and test it. (see the objectives listed above). You will isolate microorganisms (bacteria) from soil, then subculture one of the bacterial species to produce a pure culture and do an antibiotic study with the pure culture you develop. You must use scientific method for your study (refer to Lab 1 for steps involved in scientific method/scientific inquiry studies). At the end of the project you will submit an individual formal report (even though you are working in a group).

Your experimentation must include controls, independent and dependent variables. It should also include repetition to verify your results.

Your investigation should also incorporate the following stages of an inquiry investigation:

Stage #	Stage	Description
Stage 1	Inquisition	Stating a question to be investigated
Stage 2	Acquisition	Brainstorming possible solutions
Stage 3	Supposition	Selecting a statement to test
Stage 4	Implementation	Designing and carrying out a plan
Stage 5	Summation	Collecting evidence and drawing conclusions
Stage 6	Exhibition	Stating a question to be investigated

Figure 10-1. The Inquiry Cycle (Llewellyn, D., 2005)

Your laboratory instructor will provide you with further information on this inquiry experiment and methods of commencing it.

Your formal report must contain references cited using APA guidelines.

References:

Llewellyn, D. (2005). Teaching High School Science Through Inquiry. Thousand Oaks, Ca.:Corwin Press.

Tiftickjian, J.D. (2011, February 17). A Selected Chronological Bibliography of Biology and Medicine-Part II-Compiled by James Southworth Steen. Retrieved July 21, 2011 from <http://ntweb.deltastate.edu/jtift/scbm/scbm-2.html>

APPENDIX C

SCIENTIFIC METHOD LAB

Biology 231 Laboratory Manual

LAB 1 – Introduction to the Biology 231 Laboratory & Scientific Investigation

II. Introduction to Biology 231 Labs

The objective of the Biology 231 lab course is to introduce students to inquiry and scientific method. By the end of the course, students should be able to know how scientific investigations are conducted; how hypotheses are used to guide and interpret data; how experiments are used to validate previous results, test predictions, and compare theories; and how scientists can control experimental conditions to obtain evidence (Benchmarks for Scientific Literacy, AAAS Web site - www.project2061.org/tools/bsl/default.htm).

The majority of the laboratory experiments in this course are traditionally taught labs that include lab instructions and experiments already designed for you to conduct and verify known hypotheses. They will be assessed with quizzes given the week following completion of the lab.

For two of the experiments in this course you will be using inquiry learning. You will design your own experiments to answer your own questions. You will formulate hypotheses and then design and conduct tests to collect data and analyze your results. You will decide whether or not your experiments support or reject your hypotheses. You will work in small groups cooperatively. Following these labs, EACH student will submit a formal lab report for assessment. In other words, even though you may work and study in a group you must write up your own reports with your own analyses, plots and summaries. Your instructor will give you additional information on writing up formal lab reports and citing references for reports.

NOTE:

Plagiarism and cheating will not be tolerated.

Scientific Method/Scientific Inquiry

In order to complete your inquiry labs, you must have some understanding of scientific method. This is a process that scientists use to investigate a problem or phenomenon. It involves a series of systematic and sequential steps to investigate and solve a problem. A typical process of scientific method follows (Llewellyn, D., 2005):

1. State the problem or question to be solved.

2. Identify all possible variables or factors that could influence the outcome of the investigation.
3. Construct a statement or hypothesis to test.

4. Identify the manipulating variable (independent), responding variable (dependent), and controlled variables.
5. Design the procedure to test the hypothesis.
6. Determine supplies, materials, and equipment required to perform the investigation.
7. Perform the investigation and collect data.
8. Record and organize data on a table or a chart.
9. Construct a graph, label the axes, and provide a title for the plot.
10. Describe the relationship between the independent variable and the dependent variable.
11. Draw a conclusion to determine the validity of the hypothesis.
12. Prepare a formal report, PowerPoint presentation, Prezi presentation, or poster of the data or conclusion (as instructed by your instructor).
13. Communicate your findings.

Inquiry seldom follows the step-by-step procedure above but does include all of the above items.

Definitions:

Hypothesis

A hypothesis is a proposed explanation for a phenomenon, pattern, or set of observations. A hypothesis should be specific so that it can be tested thoroughly. Broad or general hypotheses are difficult and complicated to test. A sample hypothesis would be “Nitrogen containing fertilizer will increase sunflower plant height”.

Experimentation

An experiment is an investigation designed to produce results that support or reject the hypothesis being tested. It is set up with a procedure and a logical sequence of events and is conducted under very specific conditions where all variables are controlled except for the one being studied. Within an experiment, the variables of the experiment are defined, the procedure for the experiment is outlined, and controls to be used as the experiment is performed are determined.

Independent Variable

The independent variable is the **manipulating variable**. It is the variable to be tested (e.g. enzyme concentration). The investigator decides how the

independent variable will be treated during an experiment. The experimental treatment usually involves varying or changing the conditions of the independent variable. Only one independent variable may be investigated in an experiment.

Dependent Variable

The dependent variable is the **responding variable**. It is what is measured, counted or recorded in the experiment (e.g. time for starch to be digested by amylase). It is affected by (dependent upon) changes in the independent variable. More than one dependent variable may be measured in the experiment.

Controlled Variable

Controlled variables are factors in the experiment that must be held **constant** so that they do not affect the outcome of the experiment (e.g. temperature in the laboratory room, or amount of substrate used in an enzyme experiment).

Note: It is always assumed in experiments that the independent variable does actually affect the dependent variable and **this assumption must always be tested**. When you experiment you must perform at least two tests – one test should examine the effect of the independent variable on the dependent variable (**experimental treatment**) and the other test should examine factors (other than those you are testing) that may affect the dependent variable (**control treatment**). Control treatments are treatments in which the test is performed under the same conditions as the experimental treatment but minus the independent variable. It should be eliminated in control treatments or should be set at a standard value if not eliminated.

Constants

It is important in experiments to maintain all factors other than the independent variable the same. These factors are called constants.

Replication

Experiments must be repeated several times under the same conditions to obtain reliable results. When experiments are replicated many times under the same conditions, each run is called a replicate. Replicates must be independent observations, not repeated measurements of the same individual. For example if you were testing the effects of nitrogen fertilizer on sunflower growth, you would want to grow numerous sunflower plants and test them under each of the treatment conditions to check their growth to ensure that results are reproducible. When experiments are repeated many times and consistent results are obtained on many runs, you are able to make more accurate assessments about your hypothesis.

Hypotheses

Once your data is collected and analyzed, your results may support or reject your hypothesis. If results are consistent with your hypothesis then your hypothesis is **supported**. As other researchers and students repeat your experiment and reproduce your results, more evidence to support your hypothesis is obtained. However just because evidence supports your hypothesis, it doesn't necessarily mean that your hypothesis is **proven**. There is always the possibility that additional testing, experiments, or advances in technology can present alternative ways of interpreting the data and disproving your hypothesis. If your data does not support your hypothesis or you obtain non-reproducible or inconsistent results, then your hypothesis is said to be **rejected**.

APPENDIX D

ENZYME PRE-LAB QUIZ

Biology 231 – Inquiry Lab I – Enzymes Name: _____
Winter 2012

Pre Lab Survey

Note: Participation is Voluntary

Your mark will not be affected whether or not you participate in this survey

1. Name the enzyme you will investigate in the lab this week:
 - (a) coagulase
 - (b) hydrogen peroxidase
 - (c) oxygenase
 - (d) carbon dioxide
 - (e) catalase

2. Name an independent variable in the experiment you will perform this week:
 - (a) time for breakdown of enzyme
 - (b) concentration of enzyme
 - (c) pH
 - (d) temperature
 - (e) metal ion concentration

3. A filter paper disc saturated with enzyme takes 30 seconds to rise a distance of 60 mm in a vial of substrate. What is the reaction rate of breakdown of substrate by the enzyme?
 - (a) 1800 mm/sec
 - (b) 1.0 mm/sec
 - (c) 2.0 mm/sec
 - (d) 0.0 mm/sec
 - (e) 0.5 mm/sec

4. The following can denature an enzyme:
 - (a) enzyme concentration of greater than 75%
 - (b) substrate concentration of 7
 - (c) pH of 2
 - (d) all of the above
 - (e) none of the above

5. Define the term 'enzyme'.

APPENDIX E

ENZYME POST-LAB QUIZ

Biology 231 – Inquiry Lab I – Enzymes Name: _____
Winter 2012

Post Lab Survey

Note: Participation is Voluntary

Your mark will not be affected whether or not you participate in this survey

1. Name the enzyme you will investigate in the lab this week:
 - (a) coagulase
 - (b) hydrogen peroxidase
 - (c) oxygenase
 - (d) carbon dioxide
 - (e) catalase
2. Name an independent variable in the experiment you will perform this week:
 - (a) time for breakdown of enzyme
 - (b) concentration of enzyme
 - (c) pH
 - (d) temperature
 - (e) metal ion concentration
3. A filter paper disc saturated with enzyme takes 30 seconds to rise a distance of 60 mm in a vial of substrate. What is the reaction rate of breakdown of substrate by the enzyme?
 - (a) 1800 mm/sec
 - (b) 1.0 mm/sec
 - (c) 2.0 mm/sec
 - (d) 0.0 mm/sec
 - (e) 0.5 mm/sec
4. The following can denature an enzyme:
 - (a) Enzyme concentration of greater than 75%
 - (b) substrate concentration of 7
 - (c) pH of 2
 - (d) all of the above
 - (e) none of the above
5. Define the term 'enzyme'.

APPENDIX F

BIOLOGY 231 LAB EXAM 1
TREATMENT QUESTION ON ENZYMES

Biology 231 Lab Examination No. 1 – Midterm Lab Exam – Enzyme Question

I. ENZYME ANALYSIS:

(Marks)

1. Lab # 2 in Biology 231 investigated enzyme activity. Name the molecule that acted as the:
 - (1) (i) Substrate(s) : _____
 - (1) (ii) Enzyme: _____
 - (1) (iii) Product(s): _____
 - (3) (iv) In your experiment it takes 35 seconds for a disc saturated with the enzyme to rise a distance of 68 mm. What is the rate of reaction for the enzyme? Show the formula used.

2. After doing the enzyme labs in Biology 231, you become excited about enzymatic reactions and decide to do some experimenting of your own. You do some research and become interested in thermophilic (heat-loving) bacteria that live in the Banff National Park hot springs where temperatures range from 60-80°C.

You obtain a sample of an enzyme from the thermophilic bacteria, some substrate and a method to measure the rate of product formation. You then design an experiment to determine the effect of temperature on the rate of reaction for this bacterial enzyme.

 - (2) (i) Based on the information provided in this question, what is a possible hypothesis for the proposed experiment described above?

 - (1) (ii) Name an independent variable in the proposed experiment.

- (1) (iii) Define the term 'dependent variable' in an experiment.

Biology 231 Lab Examination No. 1 – Midterm Lab Exam – Enzyme Question (cont'd)

- (2) (iv) List **two** factors that should be held constant (controlled variables) in this proposed experiment.

(i)

(ii)

- (6) (v) After performing several repetitions of your experiment, you obtain the following set of data for the thermophilic bacterial enzyme

Temperature (°C)	Rate of Enzyme Reaction (g/min)
10	0.01
20	0.03
30	0.05
40	0.10
50	0.90
60	2.20
70	3.90
80	4.00
90	0.20

Construct a complete line graph of this data on the graph paper provided.

- (3) (vi) What conclusion(s) can you draw about this experiment based on your results?

APPENDIX G

BIOLOGY 231 LAB EXAM 1
NON-TREATMENT QUESTION ON MEIOSIS

III: CELL DIVISION & GENETICS:

- (4) 1. (i) Label the following diagram of *Ascaris* in the **Metaphase II** stage of meiosis.
- (4) (ii) Briefly describe what is occurring at this stage.
- (1) (iii) Is this cell haploid or diploid?
- (1) (iv) Adult *Ascaris* are $2n=4$. How many chromatids are present in the cell in part (i)?
- (1) (v) This cell in part (i) is best termed a: (circle the correct letter)
(a) ova
(b) ootid
(c) secondary oocyte
(d) oogenesis
(e) primary oocyte

APPENDIX H

ANTIBIOTIC PRE-LAB QUIZ

(ii)

APPENDIX I

ANTIBIOTIC POST-LAB QUIZ

APPENDIX J

EXPERIMENTAL DESIGN GRADING RUBRIC
INQUIRY LAB I & II

BIOLOGY 231 - EXPERIMENTAL DESIGN GRADING RUBRIC
INQUIRY LAB I – ENZYMES & INQUIRY LAB II - ANTIBIOTICS

EXPERIMENTAL DESIGN MARK BREAKDOWN:

<u>Marks:</u>	<u>Questions that student must answer in his/her experimental design:</u>
(2)	1. What problem/question are you investigating?
(2)	2. Based on information from your group, what is the hypothesis for the experiment you are designing?
(2)	3. What is the independent variable in your experiment?
(2)	4. What is the dependent variable in your experiment?
(2)	5. What is/are the controls? What is a control? Why should your experiment have controls?
(2)	6. What variables are you maintaining constant in your experiment? Why should these variables be kept constant?
(2)	7. Do you have replicates for each treatment? Why or why not?
(4)	8. What is your step-by-step procedure for your experiment? How long will your procedure take? What special equipment/chemicals/materials will you require? Your procedure should be detailed enough so that other trained people could follow it.
(2)	9. How will you record your data and present it? (e.g. What will your data tables look like, how will you draw plots, e.g. line graphs, bar graphs. Can you use statistics to present your data?)

Total: ____/20 Marks

APPENDIX K

FORMAL REPORT GRADING RUBRIC - ENZYMES

Discussion	Complete analysis of what the lab actually accomplished. Sources of error discussed. Writer discusses whether the lab results were expected and if not, why. Analysis is grounded in good science and is easy to understand. The analysis is correct. (20 points)	Analysis of what the lab accomplished is present but contains errors. Sources of error not discussed. Unpredictable results not discussed. Difficulty in understanding analysis or analysis not grounded in good science. (19 - 1 points)	Data analysis in error or not grounded in science. Sources of error and unpredictable results not discussed. Discussion missing. (0 points)	/20
Conclusion	Concise statement grounded in good science that is an accurate statement of what the lab accomplished. Ideas are logical and organized and supported by the data, research and data analysis. (5 points)	Ideas somewhat logical and organized and rely on students' research to answer the original problem. Interpretation of data analysis, research not supported or in error. (3 or 4 points)	Ideas not logical or organized and are not supported by students' research. Student is not able or does not answer the original question/problem. (2 to 0 points)	/5
References	Present & Properly cited (2 points)	Present but not properly cited (1 point)	Not present (0 points)	/2
Presentation	Extremely neat, follows guidelines, proper grammar/tense & easy to read. (3 points)	Neat & easy to read. Errors in following guidelines or tense used. (2 or 1 points)	Lab report is not neat, not typed & does not follow specifications. (0 points)	/3
Total:				/55

Formal Lab Report Total: _____/55

Experimental Design Report: _____/20

Total Enzyme Lab: _____/75 = ____/5% Bio 231 course grade

APPENDIX L

FORMAL REPORT GRADING RUBRIC - ANTIBIOTIC STUDY

APPENDIX M

BIOLOGY 231 LABORATORY EXAMINATION 2,
TREATMENT QUESTION ON ANTIBIOTIC RESISTANCE & SENSITIVITY

Biology 231 Laboratory Examination No. 2 – Antibiotic Question:

Question No. 11

Marks:

(1) 11 a. Define the term 'antibiotic'.

(1) 11 b. Name an antibiotic.

(2) 11 c. What is meant by antibiotic sensitivity testing?