ASSESSING UNIVERSITY BIOLOGY STUDENTS' CRITICAL THINKING SKILLS RESULTING FROM TEAM-BASED LEARNING WITH CASE STUDIES IN THE CLASSROOM

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ABSTRACT

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ASSESSING UNIVERSITY BIOLOGY STUDENTS'
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Research was conducted to measure the effectiveness of new course assessments to increase post-semester exam scores and critical thinking abilities of undergraduate students enrolled in a large lecture Principles of Biology course. New complex problem scenarios were designed to reinforce biological topics studied with team-based learning (TBL) and to promote development of higher order thinking skills. The new problem scenarios were introduced in unit exams following a unit of study with TBL. Research results showed significant increases in student post-semester test scores for specific TBL-aligned questions when compared to previous semester student scores. This result validated the hypothesis that student content knowledge scores would increase due to new TBL-aligned problem scenario assessments. Comparisons between students' successive problem scenario scores showed significant differences. Comparisons of student scores with different science backgrounds were not significant for posttest scores and problem scenario essays.

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CHAPTER I

INTRODUCTION

The ability to think critically is a characteristic employers are seeking in job applicants. A job candidate's abilities to analyze and evaluate information, think innovatively, perform logical and deductive reasoning, solve problems, and make decisions are desirable attributes according to a survey conducted on behalf of The Association of American Colleges and Universities (Hart Research Associates, 2013). The majority of respondents to the survey, primarily business and nonprofit leaders, agreed that clear communication, critical thinking abilities, and problem solving abilities were more important to employers than the undergraduate major of the job candidate. To ensure that job applicants attain these skills, higher education institutions are being held accountable by state legislatures to effectively integrate elements into course curricula that will promote student development in critical thinking and deductive reasoning.

The state of Texas established the Texas Commission on Higher Education in 1965 as the coordinating board to provide leadership and coordination for the Texas higher education system (The Legislature Reference Library of Texas, 1965). Now known as the Texas Higher Education Coordinating Board (THECB), this board adopts rules regarding the core curriculum including six core objectives with skills development in critical thinking, communication, teamwork, quantitative and empirical data manipulation, social and personal responsibility. The THECB has mandated that the life and physical science component area of the core curriculum should include development in four of the six core objective areas: 1) communication, 2) teamwork, 3) quantitative and empirical data manipulation, and 4) critical thinking (THECB, 2011).

Higher education institutions are under pressure to graduate students with the requisite critical thinking skills being sought by employers and to ensure the integration of appropriate activities in the classroom, which will promote and build on mandated skills to satisfy state requirements. As higher education institutions seek to comply with state regulations, they face challenges in four key areas: 1) defining and describing critical thinking skills that align to course learning outcomes; 2) identifying resources to create and integrate effective teaching and learning tools that promote critical thinking; 3) engaging student interest and participation in classroom activities; and 4) building and utilizing assessments that measure student's critical thinking abilities.

Defining Critical Thinking

Determining what constitutes critical thinking with alignment to course outcomes is a challenge educators' face. Critical thinking has been described as a high order of cognitive ability while critical thinkers are referred to as innovative, problem solvers and effective decision makers (Kek & Huijser, 2011; Pedrosa-de-Jesus, Moreira, Lopes, & Watts, 2014; Walker, 2003). Professional organizations have developed definitions and descriptions of critical thinking and of the skill sets required to be an actively engaged critical thinker. The Critical Thinking Community, a nonprofit organization with a mission to assist educational change through quality of thinking, claims that critical thinking is self-directed, self-disciplined, self-monitored, and self-corrective (Paul & Elder, 2008). They trace the idea of critical thinking back to the days of Socrates and point to his strategy of "probing questioning" into exploring assumptions and beliefs and examining supporting evidence before accepting information as factual knowledge.

In 1990, the American Philosophical Society convened an expert panel of educators to explore the role of critical thinking in education. Led by Peter Facione, this group published their ideas and findings in "The Delphi Report" (Critical Thinking: A Statement of Expert Consensus for Purposes of Educational Assessment and Instruction) (Facione, 1990). The group concluded and defined critical thinking as purposeful, self-regulatory judgment that results in interpretation, analysis, evaluation, and inference (Facione, 1990). The National Council for Excellence in Critical Thinking described critical thinking as an intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information (Scriven & Paul, 1987).

Critical thinkers inquire and question in all aspects of their lives and, according to the Center for Critical Thinking, individuals develop critical thinking by moving through a systematic series of six stages that build upon thinking skills (Elder & Paul, 1996). Beyond the definitions, which have been developed, among the characteristics of a critical thinker are the abilities to evaluate, analyze, reason, reflect, be insightful, and form judgments.

The Bloom's Taxonomy Learning Framework

One of the goals of educators is to select and design classroom activities, projects, and assignments that align to student learning outcomes and to promote the development of these thinking abilities. A learning framework formulated by Dr. Benjamin Bloom in 1956, Bloom's taxonomy, is often used by educators as a method for determining student levels of learning. Bloom's Taxonomy presents a hierarchical view of learning in which students' progress through a series of levels. There are six stages or levels of learning in the framework. Level 1 is characterized as low-level knowledge acquisition followed by comprehension and understanding of material as attainment of Level 2.

Memorization of key concepts and facts by the student can fulfill the learning at these first two levels since these are considered levels associated with simple recall of factual information. In the third level of learning of Bloom's taxonomy, referred to as application, the student has not only retained and assimilated the material but is capable of applying the knowledge to real life issues and situations. More complex, creative, and higher order thinking abilities evolve as students move up through to the top three levels of the Bloom's taxonomy. Level 4 is analysis, which represents the ability to identify, recognize trends, and organize thoughts. Level 5 is creation where the student can synthesize, design, invent, compose, and combine information in complex situations. Evaluation is the top and sixth level of the learning framework. Evaluation refers to a student's ability to assess theories, to predict outcomes, to successfully support and defend a position. The third through sixth levels of learning align to critical thinking skills (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956). For the purpose of this research, the learning outcomes from an undergraduate biology course were examined. Three biological topics were selected as the focus for critical thinking activities conducted during the semester. Bloom's taxonomy was the framework followed in creating and modeling complex problems for students to solve and for evaluating exam questions.

Challenges to Implementing Critical Thinking in the Classroom

A second challenge to implementing critical thinking in the classroom is the selection of an effective teaching and learning tool, which promotes the formation of higher order thinking abilities in students; then finding sufficient preparation time and resources to incorporate the teaching methodology into the class structure (Bissell & Lemons, 2006; Michael, 2007). As recently as 2012, a report by the President's Council of Advisors on Science and Technology (PCAST) stated that faculty still rely on traditional lecture in science courses (Herreid, 2015).

Identifying Resources and Integrating Tools to Promote Critical Thinking

Classroom formats are slowly evolving as educators sometimes turn to active learning methodologies that stimulate student collaboration and discussion while replacing the lecture format traditionally used. Active learning strategies seek to move beyond memorization and superficial understanding adopted by some students. These strategies seek to create a learner-centered environment where students collaborate and where understanding comes from within the student not from the instructor (Daniel, 2016). Examples of active learning strategies encompass reading and writing assignments, peer led team discussions, team problem solving, debates, simulations, case studies, "flipping" classrooms, and team-based learning (TBL). Regardless of which learning method is selected, the intent for using these strategies when promoting critical thinking is to provide knowledge that can be applied to real world situations.

Educators sometimes hesitate to adopt active learning strategies due to perceptions of time commitments, perceived issues with management of the class, the logistics and setup of the room where a course is held, perceived time taken away from regular class teaching, inexperience with where to find appropriate content that align to course goals, and unfamiliarity with the technology or materials required to implement the student learning environment to name a few (Michael, 2007). Students also feel the unfamiliarity of implementing active learning strategies into the classroom the first time they must work cooperatively and collaborate to learn course concepts. The student's role within the team and how they will participate can initially make students uncomfortable with a new classroom experience that involves a peer learning environment. Attendance on days a peer learning activity is scheduled may be impacted initially. Once a routine has been established and students understand expectations of the classroom teaming experience, more consistency in attendance may result (Daniel, 2016).

For this research study, two active learning strategies, TBL and case studies, were both used in a cooperative fashion to augment student learning outcomes on select biological topics. TBL, adopted by Larry Michaelsen in the late 1970s to manage group discussions in a large size class, provides a phased instructional approach to promote critical thinking (Michaelsen, Knight, & Find, 2004). This structured approach uses pre-assignments, an individual readiness assessment, a team readiness assessment, team group interactions and discussions, and team activity worksheet completion. It also requires a team consensus on a decision point as the final step in completing the TBL activity. The instructor acts as a facilitator instead of an expert lecturer and guides students versus telling students what to do next or how to think. Case studies were utilized for the TBL activity during this research. A case study was selected for inclusion with each TBL and used as the application exercise for the team discussion. The teams completed worksheets that were designed with thought- provoking questions to enhance students' understanding of the TBL biological topic.

Active learning strategies such as TBL and case studies have seen increasing usage in the classroom. The trend from traditional lecture-based approaches to student learner-centered environments has been evolving as instructors respond to the need to increase the number of Science, Technology, Engineering, and Mathematics (STEM) graduates called for by the PCAST (2012). The 2012 report by PCAST states "Studies have shown that classroom approaches that engage students as active participants improve retention of information and critical thinking skills and can significantly increase STEM-major interest and perseverance compared with conventional lecturing." Active learning strategies that allow students to collaborate and actively engage with their peers, comprehend course material better, and provide a learning environment in which students can interpret results and draw their own conclusion, are encouraged to satisfy the demand for STEM graduates in job markets (Carmichael, 2009; Freeman et al., 2014; Metoyer, Miller, Mount, & Westmoreland, 2014).

Case study teaching has become popular since case studies involve realistic, complex situations and involve students in the analysis and evaluation of a situation to reach a conclusion, answer a question, or make decisions that will solve a problem (Chaplin, 2009). Case studies are perceived as increasing student engagement and interest with course content and providing gains in critical thinking with students (Yadav et al., 2007). The development of higher order thinking skills within Bloom's taxonomy is facilitated by the use of a case studies and TBL (Bonney, 2015).

Case study instruction has been integral to business courses since introduced in the 1950s; TBL also began with business management courses (Armistead, 1984; Michaelsen et al., 2004). Business, law, medical, and healthcare courses integrating case study instruction methods have dominated research literature although there is increasing adoption of case study methods and TBL in science education. One reason for the rise in usage of case studies in science education has been the building of repositories of already created STEM case studies that instructors can choose from and incorporate into the classroom without building cases themselves. The National Center for Case Study Teaching in Science (NCCSTS) is an example of a repository available to educators. This repository was accessed as the source of case studies that were incorporated into TBL for this research. Instructors can also produce and submit their own case studies for acceptance to the repository. In one recent research study, instructors were unable to locate appropriate case studies for inclusion in their course. As a result, they wrote two new case studies to supplement two available case studies in their biology course (Bonney, 2015). All four of the case studies for that study resulted in significant improvements to individual student exam scores over scores earned by non-case study sections of students. No difference in student scores resulted between the instructor authored and Internet sourced cases. That finding is welcome news to instructors who wish to write their own case studies to satisfy their specific instructional needs. Research regarding the effectiveness of using case studies in introductory biology has shown that students gain a deeper understanding of course content and are able to apply the knowledge to new situation (Bonney, 2015; Chaplin, 2009). Both of the case studies created for the introductory biology course in the study referenced were subsequently accepted by the NCCSTS (Bonney, 2015).

Active learning strategies such as TBL and case studies can be successfully conducted with large student enrollments such as the number of students taking the undergraduate biology course during the semester when this research was conducted. Using case studies that are already produced from a repository such as those provided by the NCCSTS can minimize the preparation and implementation time for educators seeking to integrate active learning strategies in their courses.

Engaging Student Interest and Participation

A third challenge encountered by educators is motivating and engaging student interest and enthusiasm for the classroom activities. This is particularly important when the activity and/or assessment does not have a direct impact on the student (e.g., via a course grade; Stein & Haynes, 2011). Students are motivated by and invest time, interest, and energy in class activities that directly affect their grades. The impact of active learning activities on their grades and how activities are scored needs to be clearly understood by the student (Herreid, 2015). The chosen classroom exercises and activities must also be relevant to the student and be age appropriate (Parmelee & Michaelsen, 2010). Implementing active learning exercises including TBL with case studies, scenarios with writing or presentation assignments, games, or discussion groups can impact student engagement and performance but only if the student is comfortable with the requirements of the activities. When students are uncomfortable with the active learning exercise, they do not engage. An example would be the use of unfamiliar technology such as blogs and podcasts or peer review of other students' work. Students may either be uncomfortable with the technology or be in fear of peer criticism to their taped recordings and posted comments in the case of a blog (Salam & Hew, 2010).

In surveys completed by students taking this course, Principles of Biology I at Texas Woman's University, in 2014, students indicated that the use of teams helped them learn course material more than if they had studied alone (Agogo, 2015). They indicated the use of TBL and learning within a team was useful to their performance. Another study which used a questionnaire to determine the effect of gender on students' perception of case studies found that case studies were enjoyed by the all students, helped them to learn the subject, and required them to use higher order thinking as related to Bloom's taxonomy. The students also felt the case studies were relevant to the course (Murray, 2016). Females had more positive perceptions of case studies compared to their male counterparts. The category that scored the lowest by males and females was related to their perception of the usefulness of case studies to their future profession. Interspersing active learning activities with traditional lecture can create a diversified student learning environment which effectively motivates student to participate in the course, increase course attendance, and stimulate student performance.

Course Assessment Methods

The fourth challenge for educators revolves around developing effective ways to assess student performance when using active learning strategies. Creation of complex thinking questions that require students to apply learned science concepts, evaluate, and reach a correct conclusion are desirable (Bissell & Lemons, 2006). Unfortunately, a considerable amount of time may be required to construct appropriate thinking questions or development of problems and building of case scenarios to incorporate in exams. Problem-based questions which require the student to use higher order thinking skills to read, comprehend, examine, evaluate, and progress through a series of logical thinking steps to arrive at the correct answer or result are desirable. The question can be constructed to align to specific course learning outcomes. This type of question is often more difficult and time consuming to produce and score though than traditional multiple-choice questions. With large lecture groups containing hundreds of students, scoring of problem-based questions with written responses may be time consuming but worth the time and effort to produce higher order thinking abilities in students (Herreid, 2015).

Some universities have turned to standardized tests. A good standardized test may be designed to measure critical thinking and demonstrate student problem solving abilities. A drawback of a standardized test approach is the content and topics are not specifically aligned to the learning objectives of a particular science course. Standardized tests are often used to evaluate student improvement and gain in scores during a course from start to end. The test is administered as a pretest at the beginning of the semester and given again as a posttest. Standardized tests have been created, reviewed, and analyzed by large numbers of educational experts and faculty. As an example, the questions developed for the National Science Foundation's Critical Thinking Assessment Test (CAT), which is being adopted by a number of colleges and universities, has been evaluated by faculties from many educational institutions (Stein & Haynes, 2011). While the CAT is not science specific, its questions were created to address a core set of critical thinking skills. For institutions that adopt the CAT, assistance is available through training workshops that provide guidance in scoring to ensure accuracy and consistency in grading by faculty. This can be a simpler way to measure critical thinking of students although not specific to the course or concepts being taught. Another example of a multi-disciplinary standardized test, The California Critical Thinking Skills Test, a second output from the Delphi Report committee, assesses an individual's strengths in reasoning and decision-making (Pike, 1997). A disadvantage of both of these is that while they test for student thinking and reasoning abilities, they are not science specific or topic specific.

The questions measure general scientific knowledge versus specific biological concepts that are uniquely aligned to student learning outcomes of a particular course.

The choice of assessment method occasionally hinges on how many students are enrolled in the course. Examinations that include extensive writing are found more often with smaller classroom groups where scoring is manageable by an individual instructor or with the aid of a graduate teaching assistant. These types of exams with writing assessments are most often found in upper level undergraduate or graduate courses although an instructor with access to numerous graduate teaching assistants may choose these writing assignment examinations (Herreid, 2015).

While there are a variety of approaches being implemented in the classroom to promote critical thinking, institutions of higher learning and the individual instructor will continue to be challenged in which teaching methods and programs can be most efficiently and effectively incorporated in the classroom. As the real world job market demands higher order thinking abilities and legislatures seek reports showing instructors at educational institutions are meeting the critical thinking competency, educators will be accountable for ensuring graduating students possess the requisite skills for the foreseeable future.

Purpose of this Research Study

This research was conducted to determine the impact of a new assessment method with students enrolled in a Principles of Biology I course at Texas Woman's University. The new assessments took the form of problem scenarios created specifically to align to biological topics studied through TBL activities during the semester. The introduction of this new assessment methodology had a two-fold purpose: 1) to increase student scores on end of semester testing and 2) to develop or enhance student higher order thinking abilities. Measuring the effectiveness of TBL activities in increasing student performance on exams is challenging. This research took a results oriented approach analyzing student scores attained on assessments that factored directly into student grades and did not focus on questionnaires or surveys assessing student perceptions of the TBL active learning environment. Each new problem scenario and its associated grading rubric were prepared using Bloom's taxonomy of learning as a basis for the design. The scenarios required students to compose responses that showed a solid grasp of the topic and justify their deductions and conclusions. The problem scenario and grading rubric aligned to Bloom's higher order learning objectives with Levels 4, 5, and 6. The problems reinforced the biological topic and required students to utilize higher order learning skills to solve the given problem and earn the maximum number of points.

The three hypotheses tested for this study were: (1) TBL activities positively affect student content knowledge for the specific case study aligned unit learning objective, (2) student scores on individual exam essay questions pertaining to student learning objectives for osmosis, cellular respiration, and genetics (the three biological topics that served as the subject of the TBLs and case studies) will show progress in critical thinking skills on each successive exam, and (3) students who have completed four or more science courses will score better on pre and posttests and on exam essay questions.

CHAPTER II

METHODS AND MATERIALS

Course Background

This IRB-approved study was conducted during the fall semester of 2015 with students enrolled in a Principles of Biology I undergraduate biology majors course at Texas Woman's University as the participants. This introductory course to biological concepts and organization is typically one of the first science courses students are exposed to at the university level. The intended audience for this course is individuals majoring in science and most are beginning their freshman or sophomore year in college. The course is offered in both fall and spring semesters with higher enrollments in fall semesters. Over 200 students typically register in a fall semester. The class convenes in a large theater style auditorium bi-weekly for 80 minutes and the same instructor has taught the course for 8 years.

The material for this course was divided into four units of study. The units of study were taught using traditional lecture with guided notes, online homework assignments, class participation via personal answer devices (commonly referred to as "clickers"), and through TBL activities. Student performance for this course was measured through homework assignments, unit quizzes, unit exams, TBL activities, and interactive clicker assessments. Starting with the fall semester of 2014, TBL modules were introduced to the course curriculum as a method to create a peer learning environment, promote teamwork, and increase student engagement. TBL activities completed within the same 80-minute class period.

Figure 1 shows the progression of course events from the first day to the last day of the semester for the two fall semesters being compared in this study.

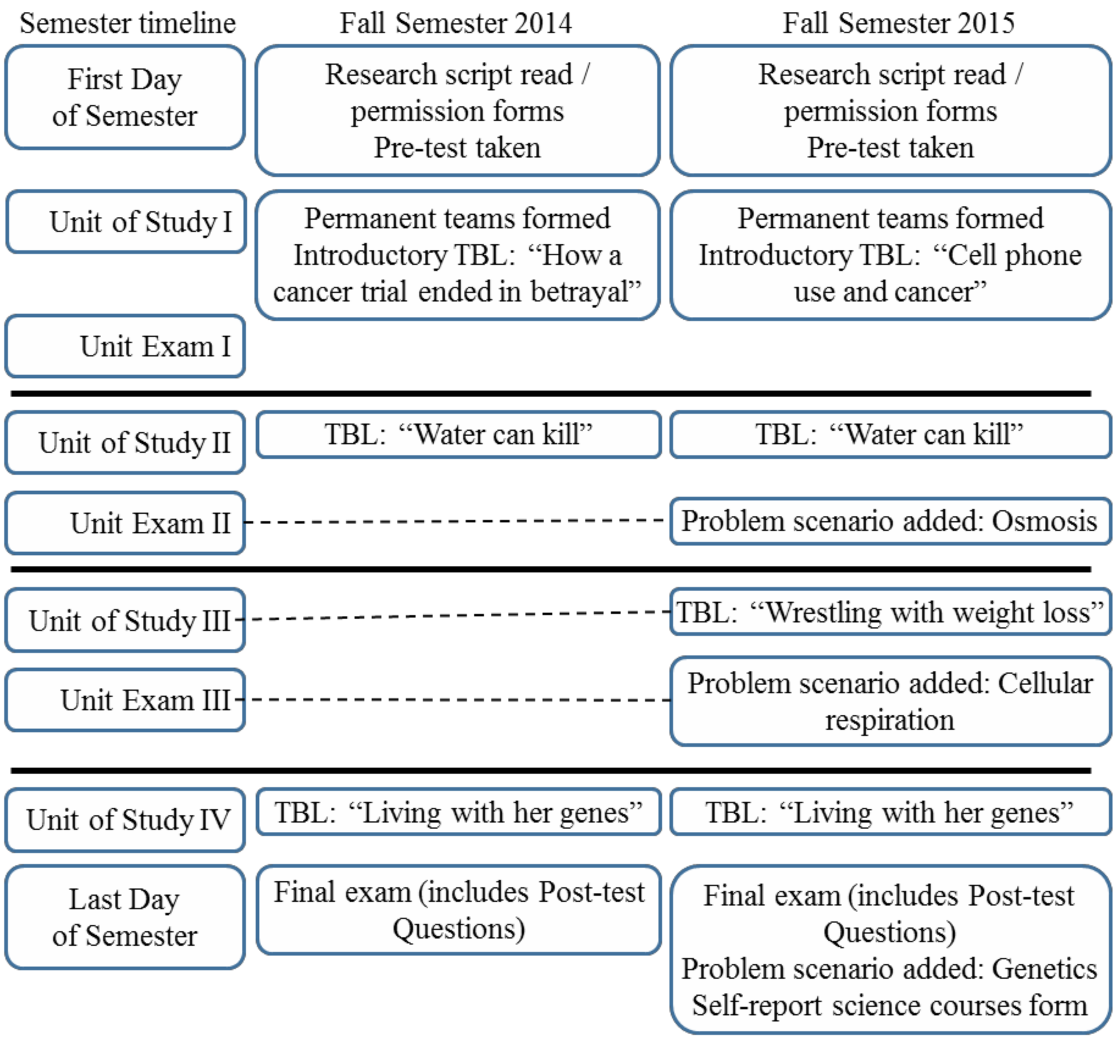

Figure 1. Timeline of course events: comparison between fall semester 2014 and 2015. The interventions designed and tested in this work in the 2015 fall semester are: a) the introductory TBL case study, b) four TBLs were conducted in the fall semester of 2015 versus only three TBLs in the fall of 2014, and c) three problem scenario assessments were added to two unit exams and the final exam in the 2015 fall semester.

On the first day of class, students were given a test of 50 multiple-choice questions that reflect the course concepts and biological topics taught during each semester. The preliminary exam was referred to as the pre-test and the instructor has given this same exam for the last 8 years. This pretest was scored. However, results were not returned to the students. Pretest scores were also not included in calculating the student's final grade for the semester. The instructor used pre-test scores and information to assess the students' level of knowledge on biological topics prior to the start of semester instruction. On the last day of class, these same 50 multiple choice pre-test questions were included in the final exam of the semester. The comprehensive final exam was worth 100 points of which 50 were the original pretest questions and 50 were based on learning objectives from all material covered in the course. For the purpose of this paper, the 50 questions are referred to as the pretest when given on the first day of the semester and referred to as the posttest when included as part of the final exam. Unlike the pretest, the 50 posttest questions were included in the final exam scores and were factored into the calculations that determine each student's final grade for the course.

During the fall of 2014, all questions on the pre and posttest were assigned a Bloom's learning level value from 1 to 6 with 1 being the lowest difficulty question and 6 being the most difficult question (Agogo, 2015). Each question was independently assigned a Bloom's level by each member of a team comprised of the instructor for the course, a colleague who taught the laboratory portion of the course, and two graduate students performing research with this course. Following individual rating of each question, the level assigned to the question by each person was compared and any discrepancies by the raters for that question were resolved. Of the 50 questions, 90% were rated Bloom's low learning level (Levels 1–2) and the remaining 10% were rated as Bloom's high learning levels (Levels 3–6).

Student Participation in the Research

All students participated in regular class activities and assignments in their Principles of Biology I lecture section during this study. Agreement to participate in this research study was voluntary. On the first day of class for the semester, students were read a script and supplied with a printed copy containing the description of the research to be conducted. Students indicated by their signature on the form that permission was granted to include their student scores anonymously for this study. They also acknowledged by their signature that all student data were analyzed following conclusion of the course and after posting of all final grades had occurred. Those students who chose not to participate in the study completed all assignments normally along with their peers. Their documents, surveys, and exams were excluded from the final data analysis. Whether the student participated or not, the research did not affect any scores or final grades assigned. Student identity was removed from pre-test, unit exams, final exams, and application exercises before analysis. No individually identifiable student data or course work were contained in reports or publications related to this study.

Students in the fall semester of 2015 were asked an additional item, to self-assess their level of previous science background. A simple form was distributed along with the final exam of the semester. Students self-reported the number of science courses they had completed prior to this course by circling one of the categories printed on the form. Their choices were 0–3 science courses, 4–6 science courses, 7–9 science courses, or 9 or more courses completed previous to taking this course. Based on responses, students were subsequently divided into two groups for analyses. One group was classified as having more science experience if they had selected any category representing four or more science courses. The number of students self-reporting as four or more science courses previously was 33. The second group of students were classified as less science experience since they had selected the category for completing three or fewer previous science courses. The number of students self-reporting in this category was 93.

Team-Based Learning Activities

Four TBL exercises were conducted during the fall research semester of 2015. Three were conducted during the comparison fall semester of 2014. During fall 2015, a TBL with case study activity was integrated with each of the four units of study. In both semesters, the first TBL conducted in each semester was intended to familiarize the students with the process and procedures to follow for the TBL activity and establish the permanent teams for the semester.

Each unit's TBL activity included a case study as the application exercise. Team worksheets were modified to suit the needs of the course. The first introductory TBL which was held during the fall of 2015 was "Cell Phone Use and Cancer" by Wilma V. Colon Parilla (this case study concerned the scientific method; Colon Parilla, 2006). The remaining three case studies implemented as part of TBL activities during fall 2015 were: "Water Can Kill" by Susan D. Hester (2013; this case study aligns to the study of osmosis in Unit II), "Wrestling with Weight Loss: The Dangers of a Weight Loss Drug" by DeSimone and Prud'homme-Généreux (2011; this case study relates to cellular respiration and ATP production in the mitochondria taught in Unit III), and "Living with Her Genes: Early Onset Familial Alzheimer's Disease" by Gildensoph, Stanford, and Wygal (2008; this case study aligns to genetics and hereditary topics in Unit IV). Case studies were obtained from the University of Buffalo case study repository called the NCCSTS (http://sciencecaseslib.buffalo.edu/cs/). Case studies were posted and made available to the students via Blackboard prior to attending class on the day scheduled for TBL activities.

Team-Based Learning and Team Formation

Students in this course were assigned to permanent teams in which they completed TBL individual quizzes, team quizzes, application exercises (case studies), and team worksheets in class. The first time students met for a TBL activity, they were divided into teams first according to their enrolled laboratory section, and second, distributed equally in sequential order to a team based on their scores earned on the pre- test. This method of team formation created heterogeneous groups where students encountered each other repeatedly during the course in their laboratory period and stimulated team participation and cooperation during TBL activities within lecture. Team size was capped to six students, which encouraged student interaction within the team. Non-consenting students were grouped into separate teams of five or six students each. In the fall semester of 2015, 36 permanent teams were formed.

Upon arrival in class on a TBL scheduled day, each student took an Individual Readiness Assessment Test (IRAT), a short quiz on the topic of the day's TBL. After individual completion of their IRAT and collection of Scantrons (scoring sheets for the IRAT quiz), all students convened with their respective teams. Each team received a manila folder containing copies of the case study and an accompanying team worksheet to complete. The team folder also contained a Team Readiness Assessment Test (TRAT), which was the same quiz as the IRAT. The TRAT was answered by the team as a unit with the use of a scratch-off card manufactured by Epstein Incorporated, which provided immediate feedback (http://www.epsteineducation.com/home/about/) Each team of students read the multiple choice questions of the TRAT, discussed possible answers from the choices given, and agreed on the correct answer before using the scratch-off card to score points for a correct answer. If the team selected and scratched off an incorrect answer block, the students on the team re-discussed the possible answers before scratching the card again with a second choice. This process continued until the correct answer was revealed.

Fewer points were awarded for each incorrect answer until the correct answer was uncovered. After the team finished the TRAT, the students turned their attentions to the case study of the day and completed the assigned team worksheet. As the final step in the TBL process, the group was required to vote for their position on a thought-provoking question related to the topic of the TBL. The team engaged in conversation to reach a consensus of opinion about the question and then voted for their choice when directed by the instructor. At the instructor's request, a representative from each team simultaneously held up a printed card containing a letter A, B, C, D, or E, which corresponded to their team's vote about the discussion question. The instructor then led a class discussion, and individual team members defended and explained their position and reasons for voting as they did.

Student Scores for Analysis

Individual student pre- and post-test scores in the fall of 2015 were gathered for comparison to historical scores achieved on these same tests by students in the fall of 2014. Comparisons of pre- and post-test scores from fall semesters 2014 and 2015 were conducted to determine whether the new problem scenario assessment introduced in the fall semester 2015 affected student end of semester post-test scores. Before analysis of the student scores and extracting specific questions for analysis, the scores were converted to a

100% scale for comparison purposes. Scores on the entire 50 questions of the pre-test and post-test were analyzed and compared between semesters; then 15 targeted multiple choice questions that aligned to topics covered in the TBL case study were extracted and analyzed separately for the two semesters. The remaining non-targeted 35 multiple choice questions of the 50 on the pre- and post-tests were separated and analyzed comparing the two semesters, as well.

Students who took this course in the fall semester 2015 were grouped for data analysis by science experience. Individual student pre and posttest scores by science experience groupings were analyzed and compared in the same manner as the between semester comparisons. All 50 questions of the pretest and posttest were compared, followed by extracting the 15 TBL-aligned target questions for comparison, and then, the 35 non-targeted questions were compared.

Unit exams were administered periodically throughout the course as each unit of study was completed. In the 2014 fall semester, each exam was composed of 50 multiple-choice questions. The comprehensive final contained 100 multiple-choice questions. A new test item, a problem scenario, was added to three of the four exams in the 2015 fall semester. Unit Exams 2 and 3 consisted of 45 questions that assessed students' level of content knowledge about the unit of study and the additional problem scenario that aligned to the topic of the TBL exercise. A comprehensive final was composed of 90 multiple-choice questions and the problem scenario. The first of the short essays regarding osmosis aligned to Unit Exam 2. The second of the short essays regarding cellular respiration and ATP production aligned to Unit Exam 3. The last short essay aligned to Unit 4 was included in the comprehensive final on the last day of the semester.

Problem Scenario Assessments

Excluding the first unit of material with TBL, all other unit exams and the final given in the fall 2015 semester included the specially written complex problem scenario that aligned to the student learning objective of the TBL. No problem scenario was created for the introductory TBL regarding the scientific method. The scenario was designed to be similar but provide a new situation for students to solve about the TBL biological topic and required students to apply previously learned knowledge to this new problem. Each problem scenario question required the student to read and understand the given situation, examine details, develop a solution, and write a narrative explaining their answer and conclusion or solution to the given situation. These essays were then scored using a standardized grading rubric to provide consistency in awarding points. Only students who attempted to answer the problem scenario and received partial points for the essay response had their scores included in the analysis. A student who did not attempt the problem scenario on the exam and received a zero score was not included in the analysis. The number of students who answered the three problem scenarios and gave permission for their data to be included in this study totaled 126 students.

The problem scenario assessment was designed specifically to align to the student learning outcome that was the subject of that unit's TBL activity and to promote higher order thinking skills. The biological topics were osmosis, cellular respiration (production of ATP), and genetics respectively. Each problem scenario was created using Bloom's taxonomy of learning as the basis for development of the scenario and aligned the grading rubric to the higher levels of analysis, synthesis, and evaluation. For each problem scenario, the individual student had to first read, comprehend, and interpret the problem.

These are characteristics of lower level Bloom's taxonomy. To earn the maximum points for each problem, a student was required to use higher order Bloom's skills. Table 1 outlines the skills, Bloom's level of learning and demonstrated proficiency for the student responses. The individual problem scenarios are included in Appendices A, B, and C. The individual objective grading rubrics created for each individual problem scenario are included in Appendices D, E, and F. Partial points were awarded depending on factors such as clarity, completeness, accuracy in the student's written response, and into what category the written response was classified.

Table 1

Problem Scenario Design and Grading Rubric Based on Bloom's Taxonomy

Skill	Poor	Fair	Good	Excellent	Bloom's Level
Compose a Narrative	Confusing, Incorrect information	Adequate but with errors	Organized thoughts, minor errors	Clear, Concise, Organized	5-Synthesize
Terminology Usage (if required)	Missing, Incorrectly applied	Partially applied, some missing	Complete, minor errors	Thorough, Correctly applied	4-Analyze
Diagram and Labeling (if required)	Missing elements of design, unable to complete	Drawing incomplete, some items missing	Design correct, minor labeling error	Accurate illustration and design	4-Analysis
Justification, Conclusion	Incorrect understanding, reasoning	Partial solution, some errors	Accurate with minor errors	Strong grasp of concepts, deductions	6-Evaluate

Following development of the scenario and rubric, the problem scenario was added to each TBL-aligned unit exam as a new measurement item within the exam. It was hypothesized that students would become familiar with answering these thought-provoking questions as the semester progressed and, therefore, scores would increase for each subsequent short essay written in response to the problem scenario presented on successive unit exams.

Within the research semester, student scores on each individual short essay were examined to determine if individual thinking skills and the ability to answer these type of thinking questions improved as the semester progressed. The short essay response was worth eight points on Unit Exams 2 and 3 and worth 10 points on Unit Exam 4. For comparison purposes, each scenario's possible point value was converted to 10 points.

The effect of the TBL activities with case studies and the effectiveness of the new assessment problem on student performance were measured by comparing the research semester student scores on pretest and posttest exam questions to the previous fall semester, which did not include the problem scenarios on unit exams. Student scores from a previous fall semester were used as the control semester for pre and posttest questions. In fall 2015, the pre and posttest questions were further analyzed by science experience groupings. Scores on pre and posttest questions and scores on short essay responses to the problem scenarios were compared by science experience.

The two main differences between the two fall semesters being compared for this study were the number of TBL activities conducted (three in 2014 and four in 2015) and the individual case studies integrated in the TBLs. The introductory TBL differed between the two fall semesters with a TBL and case study based on a cancer trial for fall 2014 and fall semester 2015 TBL included a case study about cell phone use and cancer. Two of the same case studies were used aligned to exam two and the final exam. One case study related to the study of osmosis aligned to Unit 2 and one case study related to genetics aligned to Unit 4. A fourth TBL was conducted in the fall 2015 semester that aligned to the third unit of study and focused on cellular respiration. Two unique items collected solely in fall 2015 were student self-reporting of the number of science courses they had taken prior to this course and the problem scenarios implementation as a new assessment method. The effectiveness of the problem scenarios in promoting higher content knowledge scores was a key component introduced in fall 2015.

The IBM SPSS Statistics 24 (Statistical Package for the Social Sciences) program was used to analyze all data. The explore function of the software was initially used to identify any outliers or extreme outliers and to determine if data showed a normal distribution curve. Data in the form of student scores were found to be normally distributed. One extreme outlier was identified when scores for all 50 questions of the pretest were examined for the fall semester 2015. Two extreme outliers were identified when examining the 15 targeted questions from the post-test in the fall semester 2015. Since these were the only instances where extreme outliers were noted, all student scores remained in the analyses.

Data collected include student scores earned on pre-tests and post-tests from two fall semesters and short essay points earned on three problem scenarios. The two semesters of Principles of Biology I student scores that were collected for comparisons of pre and posttest were the 2014 and 2015 fall semesters. Scores on short essays written as responses to the problem scenarios were collected from students enrolled in the course in the 2015 fall semester for analysis.

Data were summarized in Microsoft Excel. In consultation with Texas Woman's University Center for Research Design and Analysis, repeated measure analysis of variance (ANOVA) was determined to be the appropriate statistical tool for comparing the student pre and posttest scores between fall semesters and for comparing the three short essay scores from the problem scenarios. Individual student's *t*-tests were used to compare individual short essay responses by science background. All assumptions for running ANOVA were met except for a single violation of Levene's test for equality of variances on two posttest scores that were analyzed. Additional testing of assumptions was completed by running Welch's test and performing data transformations on the two columns of posttest scores. The two columns of posttest scores were converted to square root and natural log creating two new columns of alternative dependent variables for testing. Repeating the analyses with the converted columns of scores yielded similar results. ANOVA is robust to violations of Levene's assumption of homogeneity of variances (Lindman, 1974).

Repeated measure ANOVA and paired student's *t*-tests were conducted to compare each of the three short essay scores to one another and to determine changes in scores as the 2015 fall semester progressed. The student scores from the osmosis essay in unit exam two were compared to scores for the cellular respiration essay from unit exam three. Cellular respiration short essay scores from unit exam three were compared to the genetics short essay scores included on the final. Finally, the scores earned on the osmosis short essay in unit two were compared to the genetics short essay scores from the final given at the end of the semester.

Two sample assuming unequal variances student's *t*-tests were run to compare student performance based on science background groups for each short essay. This analysis compared points earned on each essay grouped by students who self-reported as completing more science courses to students who reported fewer science courses completed. The osmosis, cellular respiration, and genetics short essay points were compared between students separated into two separate groups based on science background.

CHAPTER III

RESULTS

This IRB-approved research was conducted in the fall semester of 2015. Participants in the study were university students enrolled in the Principles of Biology course at Texas Woman's University. The data collected for analysis were student scores on pretest and posttest exams and scores on short essays written by students in response to specially designed problem based scenarios created for exams. All scores were summarized and examined following the end of the semester after all grades had been posted. Only students who were present to take the pretest on the first day of class and were present and completed the final exam at the end of the semester had their scores included in this study. The student enrollment in the fall of 2015 was 204 with 158 students signing consent forms giving permission to allow their scores to be included anonymously in this study. Of the 158 consenting students, 132 completed both the pre-test exam and final exam, which included the post-test questions. The comparison and control semester was the fall of 2014 when 174 consenting students had scores for both the pre-test and the post-test questions, which were included within the final exam.

Hypothesis 1: Content Knowledge Score Comparisons

The first hypothesis predicated that TBL activities would positively affect student content knowledge, as assessed on the pre-test and post-test, for the specific unit learning objectives that served as the subjects of the TBL activities. While both fall semesters compared for this study implemented TBL with case studies as the application exercise, the research semester added a new problem scenario assessment to three selected exams following completion of the TBL for that unit of study. These problem scenarios were designed to promote critical thinking about the specific biological topics that were the focus of the TBL activities. It was hypothesized that extra emphasis in the form of a thinking problem to solve would result in higher scores on selected post-test questions that were related to the topics of the TBLs conducted during the semester.

Figure 2 is divided into six segments. Each segment contains two columns with one column of the two representing each fall semester. In each of the six segments, the left (blue) column displays the 2014 fall semester mean score above the column and the 2015 fall semester mean score is listed above the right (red) column.

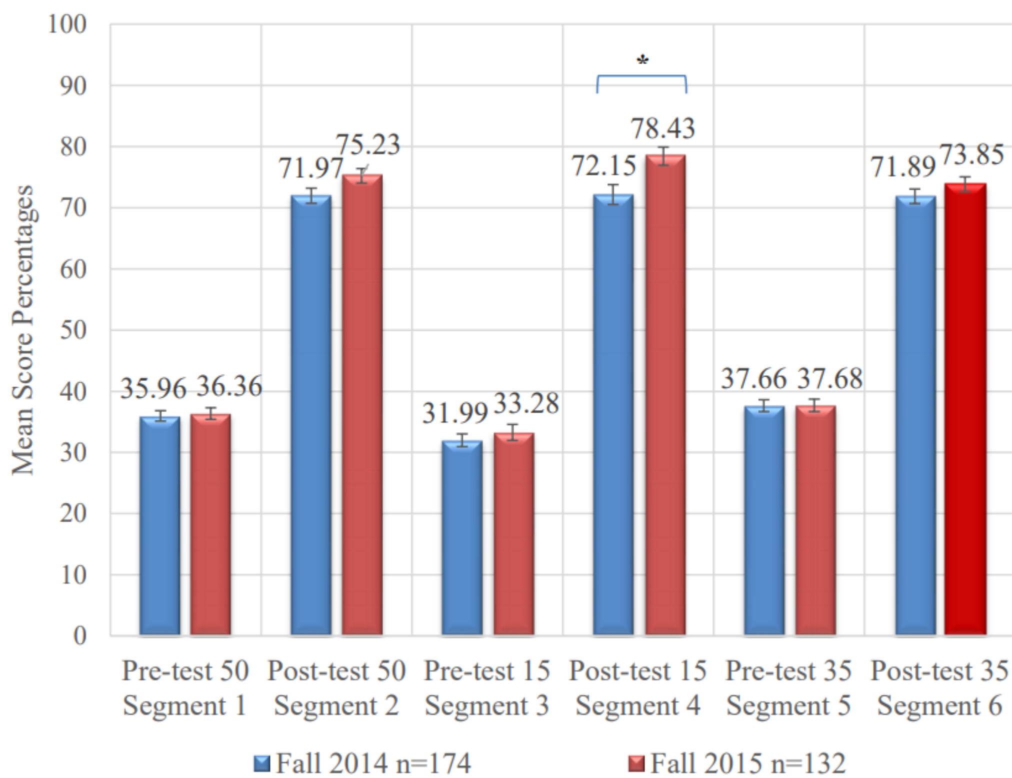

Figure 2. Comparison of pre- and post-test scores between fall semesters 2014 and 2015. Student mean score percentage comparisons are shown in each set of columns. Segments 1, 3, and 5 compare pretest to pretest scores for 2014 and 2015. Segments 2, 4, and 6 compare post-test to post-test scores. Scores on 50 questions are shown in Segments 1 and 2. Fifteen TBL-aligned target questions were extracted and compared in Segments 3 and 4. Thirty-five non-targeted questions were extracted and compared in Segments 5

and 6. Standard error bars are included for each column. An asterisk indicates a significant result for the 15 TBL-aligned target questions comparison (repeated measure ANOVA, $p = 0.006$).

H1.1: Comparison of 50 Questions from Pre and Posttests between Fall 2014 and 2015 Semesters

Segment 1 in Figure 2 displays a small +0.40% difference in the starting pre-test mean scores with 35.96% and 36.36% respectively for the two semesters. The resulting *p*-value of the two pretest mean scores for all 50 questions was not statistically significant ($F = 0.099$, $p = 0.753$). Segment 2 compares the posttest mean scores for the fall semesters and shows an increase of +3.26% between fall 2014 mean score of 71.97% and fall 2015 mean score of 75.25%. The *p*-value calculated when comparing the 50 posttest questions between the two fall semesters was not statistically significant ($F = 3.371$, $p = 0.067$).

H1.2: Comparison of 15 TBL-aligned Questions from Pre and Posttests

Segments 3 and 4 in Figure 2 compare mean scores for 15 targeted questions contained within the pre and posttests. These 15 questions were extracted and analyzed separately from the 50 for the two semesters. The 15 questions were comprised of three questions that related to osmosis, seven regarding cellular respiration and ATP production, and five on the topic of genetics. These biological topics aligned to the focus of the TBL activities and the treatment with problem scenarios on exams for the fall 2015 semester.

The Figure 2 Segment 3 set of columns, representing the pre-test mean scores for each semester, again showed little difference in the starting semester scores for the 15 questions. The mean scores of 31.99% for fall 2014 versus 33.28% for fall 2015 yields a difference of +1.29%. The *p*-value was calculated and was not statistically significant ($F = 0.604$, $p = 0.438$) Segment 4 columns which depict the post-test scores between the two fall semesters showed a positive improvement of +6.29% for fall 2015 when comparing

72.15% for 2014 to 78.43% for 2015. The *p*-value calculated between the posttest scores for the 15 TBL targeted questions was statistically significant ($F = 7.699$, $p = 0.006$).

H1.3: Comparison of 35 Non-Targeted Questions from Pre- and Post-tests

Segments 5 and 6 from Figure 2 represent a separate analysis of the 35 remaining non-targeted questions on the pre-test and again for the post-test after the 15 targeted questions scores were removed. The fifth segment of columns compares the pre-test mean scores between fall semesters with 37.66% mean score for fall 2014 and 37.68% mean score for fall 2015. This yields a negligible difference of 0.02% for starting mean scores and a *p*-value, which is not statistically significant ($F = 0.000$, $p = 0.987$). Segment 6 shows the between fall semesters posttest mean scores with fall 2014 of 71.89% as opposed to 73.85% for fall 2015. This post to posttest comparison yields a slight posttest score improvement of +1.96% in fall 2015 and a *p*-value, which is not statistically significant ($F = 1.281$, $p = 0.259$).

The comparison of pretest-to-pretest and posttest-to-posttest mean scores for the two fall semesters resulted in one statistically significant *p*-value in Segment 4 of Figure 2. The significant *p*-value result was found when comparing post-test scores for the 15 targeted questions which align to the topics focused on with TBL activities and the new problem scenario assessments introduced in the fall of 2015.

Detailed information about correct answer percentages by each question for the 15 TBL targeted pre and posttest questions related to osmosis, cellular respiration, and genetics is shown in Table 2. The Bloom's rating assigned is shown in the left column.

Table 2

Fifteen TBL-aligned Individual Questions Correct Answers by Fall Semester

Fall Semesters	2014 % change *n* = 174	2015 % change *n* = 132	% change difference 2015 minus 2014
Osmosis Q1 Blooms rating 3	20.1	18.9	-1.2
Osmosis Q2 Blooms rating 6	12.6	17.4	+4.8
Osmosis Q3 Blooms rating 3	42.5	45.5	+3.0
ATP Q1 Blooms rating 1	69.0	75.0	+6.0
ATP Q2 Blooms rating 1	55.7	61.4	+5.6
ATP Q3 Blooms rating 1	33.9	51.5	+17.6
ATP Q4 Blooms rating 1	44.3	56.8	+12.6
ATP Q5 Blooms rating 1	48.3	45.5	-2.8
ATP Q6 Blooms rating 2	62.6	58.3	-4.3
ATP Q7 Blooms rating 2	51.7	49.2	-2.5
Genetics Q1 Blooms rating 3	-5.2	3.8	+9.0
Genetics Q2 Blooms rating 3	28.7	26.5	-2.2
Genetics Q3 Blooms rating 3	50.0	61.4	+11.4
Genetics Q4 Blooms rating 5	47.7	58.3	+10.6
Genetics Q5 Blooms rating 5	39.7	47.7	+8.0

Note. The percentage change in number of correct answers on 15 targeted questions is shown. The percent change was calculated by subtracting the starting pre-test scores from the post-test scores. Three questions were related to the biological topic of osmosis, seven questions related to cellular respiration (ATP production), and five questions related to genetics. Bloom's rating assigned by a team of educators and graduate students to each question is also displayed.

For 10 of the 15 questions, the percentage increase was higher for students in the fall semester of 2015 than the percentage of students with increases in the previous fall. There were five questions that students in the fall semester 2014 answered correctly as compared to the 2015 fall semester students. In each of the five instances where the 2014 students had greater numbers of correct answers, the difference in percentage gains comparing 2014 to 2015 was 4.3% or less. One anomaly in 2014 fall semester percentages was noted; the percentage of students who gave correct answers was higher on the pretest in that fall semester than the posttest resulting in a negative percentage change of -5.2%. Of the 10 questions where the percentage change was higher for 2015 fall semester students, the difference in percentage points gained on one of the questions was 17.6% higher with four other questions showing percentage gains of 12.6%, 11.4%, 10.6%, and 9.0% respectively. Fall semester 2015 students had significantly more correct answers on the 15 TBL-aligned biological questions when comparing pre- to post-test answers.

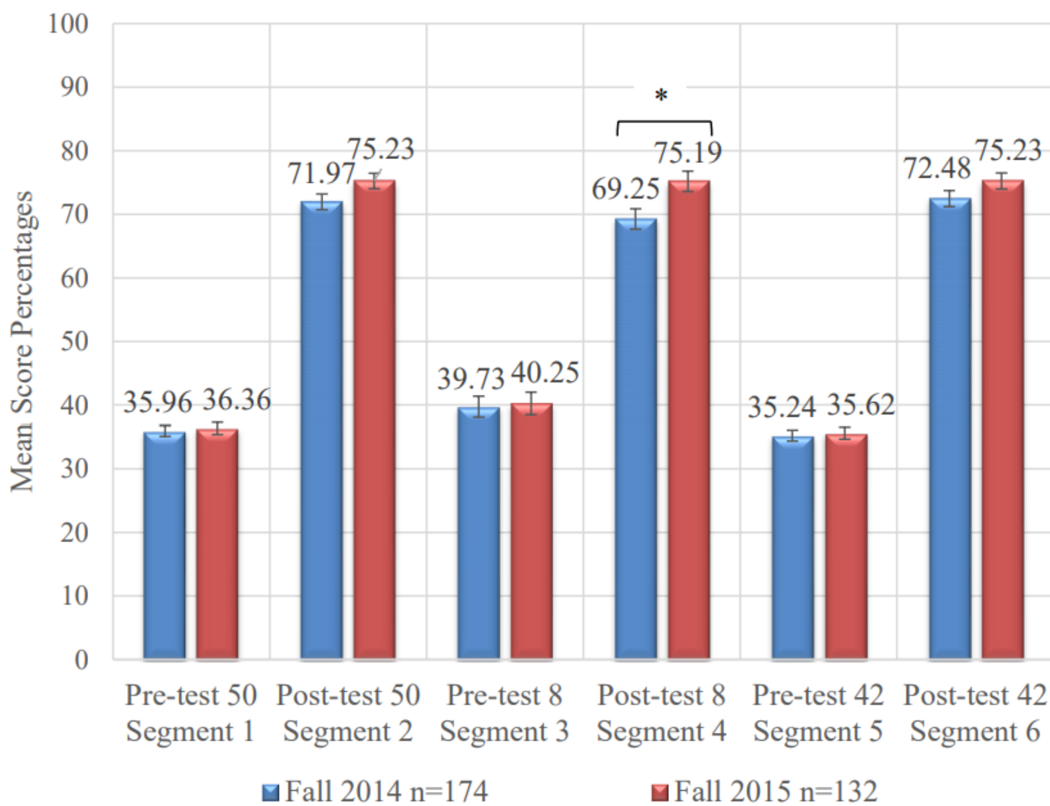

Figure 3. Comparison of pre and posttest scores between fall semesters - eight TBL-aligned. Fifty questions are compared, then eight TBL-aligned target questions, then 42 non-targeted questions. Segment 4 comparing posttest scores for the two semesters was the only significant result. (Repeated measure ANOVA, $p = 0.045$).

Since two of the TBLs were used in successive fall semesters, an additional pre and posttest analyses of eight questions that align to the topics of osmosis and genetics only is shown in Figure 3. These two biological topics were the focus of TBL activities in both fall semesters of 2014 and 2015. The seven questions on the pretest and posttest related to cellular respiration were excluded from this analysis. The eight questions analysis between fall semesters were statistically significant for posttest comparisons. The p-value of 0.045 was statistically significant for the eight TBL-aligned questions. The comparison of the remaining 42 questions with $p = 0.179$ was not significant between the two fall semesters.

Hypothesis 2: Comparison of Problem Scenario Scores on Successive Exams (Fall 2015)

The second hypothesis predicated that student scores on individual essays pertaining to student learning objectives for osmosis, cellular respiration, and genetics would show progress in critical thinking skills on each successive exam essay.

The problem scenarios were introduced as a new measurement in the 2015 fall semester to provide increased emphasis about the biological topics of the TBL activity held during each unit of study. Unit Exam 1 did not include a problem scenario and therefore, is not represented in the results. Unit Exam 2 contained a problem scenario worth eight points related to the biological topic of osmosis, Unit Exam 3 contained a problem scenario worth eight points regarding cellular respiration, and the production of ATP, and the final exam contained three separate genetics problem scenarios worth a total of 10 points. Student scores were normalized to 10 points for analysis purposes.

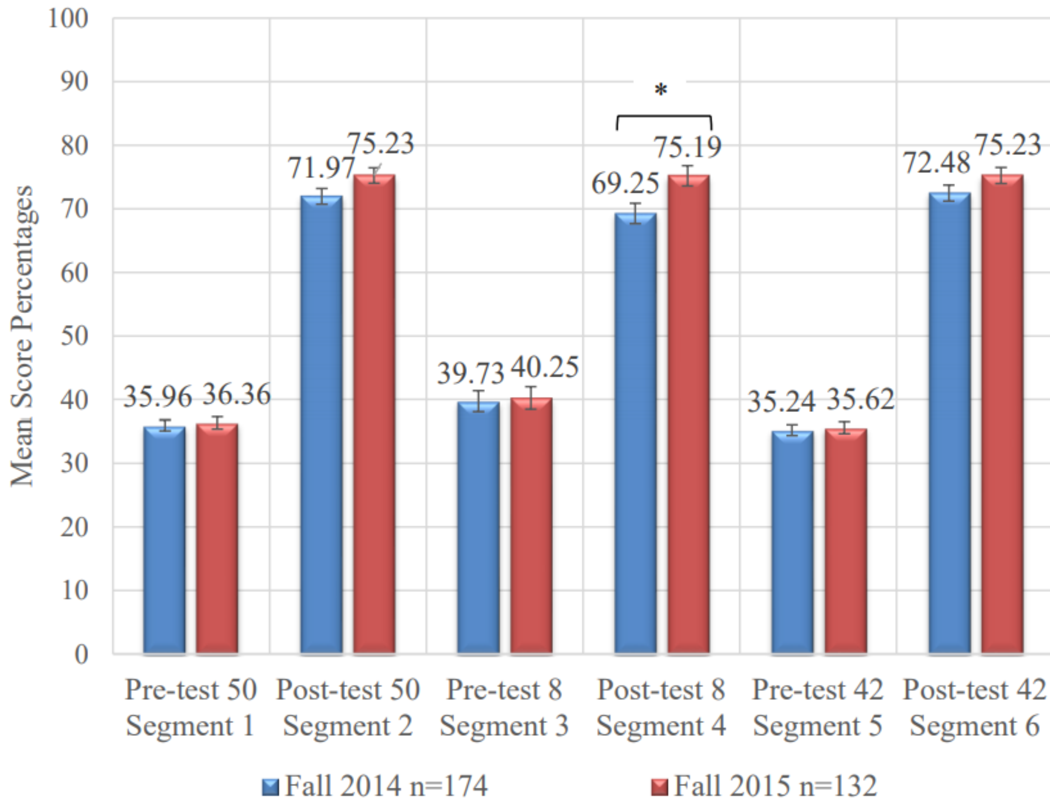

Figure 4. Student scores on problem scenario short essays for fall 2015. Data represent mean scores earned by 126 students for each problem scenario short essay. Standard error bars are included. An asterisk above the column indicates a statistically significant found with repeated measure ANOVA. The decrease from the osmosis essay to the cell respiration essay resulted with $p = 0.003$. The increase from the cell respiration to genetics essay was significant with $p < 0.001$. The comparison of the osmosis essay to the genetics essay was significant with $p = 0.047$.

Figure 4 displays the mean scores for each of the three short essays written by 126 students in response to the unit exam problem scenarios given during the fall semester 2015. Students earned a mean score of 5.69 points on the osmosis essay, experienced a decline of -0.68 to 5.01 points for the cellular respiration essay, and achieved the highest mean score on the genetics essay with 6.18 points.

The first comparison between the scores on the osmosis essay to the cellular respiration essay using a paired student's *t*-test with equal variance yielded $p = 0.003$. This was statistically significant even though the points represent a decrease from the first of the problem scenarios short essays to the points earned on the second short essay regarding cellular respiration. In comparing points for the cellular respiration short essay to the genetics short essay written on the final exam, the points increased +1.17 from 5.01 to 6.18. The paired student's *t*-test with equal variance resulted in a $p < 0.001$, which is statistically significant. The final comparison of the osmosis short essay scores to the genetics short essay also showed an increase +0.49 from 5.69 to 6.18 points for the semester. This comparison of the first to the last essays using a paired Student's *t*-test with equal variance yielded a *p*-value of 0.047, which is statistically significant.

In comparing each of the short essay scores to one another, all three comparisons for the 126 students in the fall of 2015 resulted in a statistically significant value; although the analysis of the osmosis to cellular respiration short essays resulted in a decrease in points.

Hypothesis 3: Comparison of Pre- and Post-test Scores by Science Background (Fall 2015)

The third hypothesis for this research study predicted that students who self-reported to have completed four or more science courses would score higher on the pretest and the posttest and on the individual short essays from the three exam problem scenarios. Figure 5 compares the pre- and post-test mean scores within the fall semester 2015 for two groups of students that are divided based on the number of self-reported science courses taken previous to this course. In the research semester, the number of students who had taken three or fewer science courses before this course was 98 students and 34 students indicated they had taken four or more science courses previously.

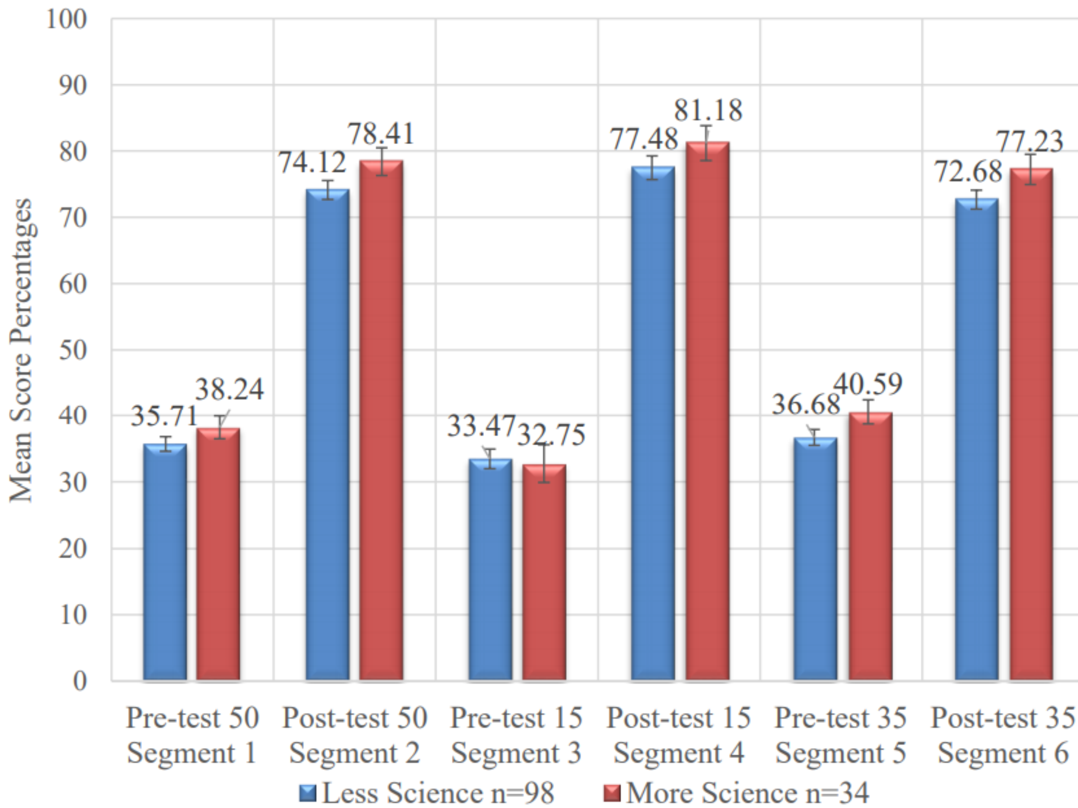

Figure 5. Comparison of pre-test and post-test mean score percentages by science background for fall 2015. Segments 1, 3, and 5 compare pretest to pretest mean score percentages. Segments 2, 4, and 6 compare posttest to posttest mean score percentages. Comparison are shown for all 50 questions, 15 TBL-aligned questions, and 35 non-targeted questions. Standard error bars are included. Repeated measure ANOVA was performed for all comparisons with no significant results.

H3.1: Comparison of 50 Questions from Pre- and Post-tests by Science Background

Figure 5 Segment 1 shows that students with three or fewer science courses previously had a mean score of 35.71% on the full 50 questions of the pre-test versus 38.24% for the students with four or more previous science courses. The difference in the pre-test scores within the 2015 fall semester was +2.53% higher for students with more science courses. The *p*-value calculated for this difference was 0.245 and not considered statistically significant (F = 1.365, p = 0.245). Segment 2 compared the posttest mean scores achieved for the entire 50 questions on the post-test between the two groups of students with differing science backgrounds. The less science students achieved a 74.12% mean score on the posttest while the students with more science courses achieved a 78.41% mean score for a difference of +4.29%. This percentage difference in mean scores yielded a *p*-value not statistically significant ($F = 2.468$, $p = 0.119$).

H3.2: Comparison of 15 TBL-aligned Questions from Pre and Posttests by Science Background

Segment 3 and segment 4 compared the pre to pretest mean scores and post to posttest mean scores for the two groups of students with different science experience but examined only the 15 TBL targeted questions that aligned to the student learning objectives of osmosis, cellular respiration, and genetics. Students with less science experience started with mean score of 33.47% while the student more science experience had a lower starting mean score on the pre-test with 32.75%. This difference of -0.72% between the two groups with differing science backgrounds yielded a *p*-value of 0.811 which was not statistically significant. ($F = 0.058$, $p = 0.811$). A comparison of the post-test mean scores for these two science background groups showed the less science-experienced students achieved a posttest mean score of 77.48% as compared to the 81.18% achieved by the more science experienced students. The +3.70% difference in the post-test mean scores showed a *p*-value which was not a significant difference ($F = 1.177$, $p = 0.280$).

H3.3: Comparison of 35 Non-Targeted Questions from Pre and Posttests by Science Background

The last two segments, Segments 5 and 6 respectively compared pretest and posttest mean scores by science courses taken for the remaining 35 questions that were not the target of the TBL activities and short essay assessment method. Students with less science courses taken achieved a pre-test mean score of 36.68% versus the 40.59% that the more science experienced students scored. The difference of +3.91% and *p*-value of 0.092 is not significant ($F = 2.884$, $p = 0.092$). Comparing the post-test mean scores for these two science-based groups resulted in 72.68% for students with less science experience and 77.23% for students with more science experience for a difference of +4.55%. The *p*-value calculated for the post- to post-test scores for the non-targeted 35 questions was not statistically significant ($F = 2.681$, $p = 0.104$).

H3.4: Comparison of Student Scores on Problem Scenarios by Science Background

Students in the fall semester 2015 self-reported the number of science courses they had completed prior to enrolling in the Principles of Biology I course. Of the 126 students who attempted all three problem scenarios and earned a point score, 93 students self-reported as completing three or fewer science courses previously. Of the students, 33 reported to have completed four or more science courses prior to the fall semester 2015. Figure 6 shows the results of the short essay results by science experience.

Comparisons of points earned on the osmosis problem scenario essay to the next exam essay regarding cellular respiration, student scores decreased for both science-based groups of students; those who had taken fewer science courses and those who had taken more science courses previously. The point scores for the cellular respiration short essay was similar for both groups of students earning 4.99 points for less science and 5.06 points for more science experienced. The students completing fewer science courses previously experienced a decline in points from 5.69 points on the osmosis essay to 4.99 points on the cellular respiration essay, a decrease of -0.70 points. The students self-reporting with more science courses previously completed decreased from 5.83 to 5.06 points, a -0.77 point decline. Both groups of students had a similar size decline in points earned. This decrease in points from the osmosis problem scenario essay to the cellular respiration short essay was statistically significant for the less science students with a *p*-value of 0.006. The point decrease was not statistically significant for the more science experienced students with $p = 0.174$.

Student scores rose again when comparing the cellular respiration short essay points achieved to the genetics short essay responses. Students with less science courses increased from 4.99 to 5.96, a positive +0.97 improvement; almost a full point. Students with more science courses previously improved substantially from 5.06 on the cellular respiration essay to 6.80 points earned on the genetics short essay, a positive +1.74 points increase. The *p*-value calculated for both science-based groups of students' point increases was statistically significant with $p<0.001$ when comparing the difference in points.

Comparing student scores on the first problem scenario short essay regarding osmosis to the genetics short essay points awarded also yielded increases for both science-based groups of students. Students with less science course completion improved from 5.65 to 5.96 points, a +0.31 point increase. The 33 students with more science courses completed increased from 5.83 to 6.80 points, a +0.97 increase, again, nearly a full point improvement from the beginning osmosis essay to the final genetics essay. Calculating whether these increases were statistically significant resulted in a $p = 0.256$ for students with less science experience and a $p = 0.065$ for students with more science experience. Neither *p*-value calculations for the increases from the osmosis short essay points to the genetics short essay points were statistically significant.

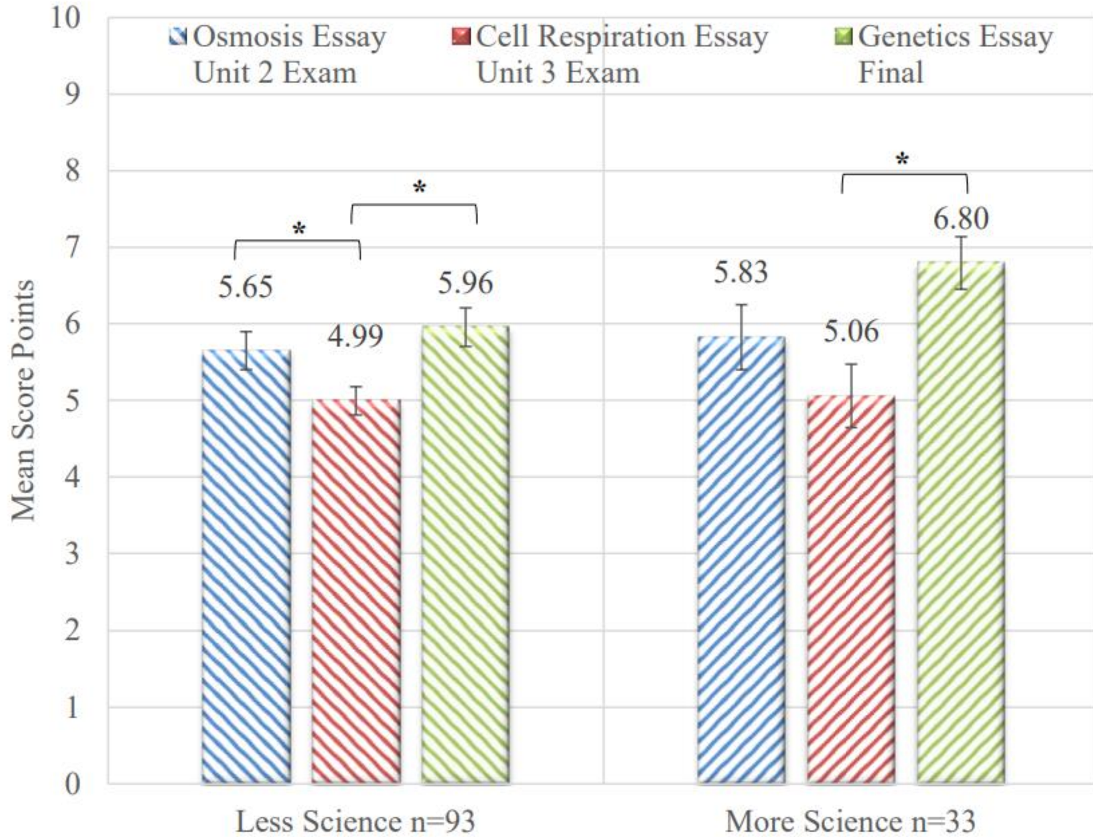

Figure 6. Comparison of individual problem scenario scores by science background. Each set of three columns represents student mean scores on each of three problem scenario compared to the next. The three left columns represent students self-reporting with less science and the three right group of columns represent students self-reporting with more science. a) Less science students comparison of osmosis essay to cell respiration was significant with $p = 0.006$. The mean scores from cell respiration to genetics were significant with $p < 0.001$. b) More science students have one significant result for the comparison of cell respiration to genetics with $p < 0.001$.

A summary of all significant results from this research is compiled in Table 3.

Table 3

Statistically Significant Research Findings Summary

Comparison between fall semesters of mean score percentages on TBL-aligned 15 post-test to post-test targeted questions	$p = 0.006$	H1.2
Comparison between fall semesters of mean score percentages on eight TBL-aligned post-test to post-test targeted questions	$p = 0.045$	H1.2
Comparison of short essay points between osmosis (problem 2) to cellular respiration (problem 3) essays within the research semester (decrease)	$p = 0.003$	H2
Comparison of short essay points between cellular respiration (problem 3) to genetics (problem 4) essays within the research semester (increase)	$p < 0.001$	H2
Comparison of short essay points between osmosis (problem 2) to genetics (problem 4) essays within the research semester (increase)	$p = 0.047$	H2
Comparison of short essay points between osmosis (problem 2) to cellular respiration (problem 3) essays for students self- reporting less science courses taken previous to this course (decrease)	$p = 0.006$	H3
Comparison of short essay points between cellular respiration (problem 3) to genetics (problem 4) essays for students self- reporting less science courses taken previous to this course (increase)	$p < 0.001$	H3
Comparison of short essay points between cellular respiration (problem 3) to genetics (problem 4) essays for students self- reporting more science courses taken previous to this course (increase)	$p < 0.001$	H3

Note. Hypothesis number is located in the right column.

CHAPTER IV

DISCUSSION

The purpose of this study was to test the effectiveness of new assessments associated with TBL on student performance and critical thinking skills in an introductory biology course, Principles of Biology I, at Texas Woman's University. The effects were measured in two ways: 1) comparison of student scores achieved on pre- test and post-test questions and 2) analysis of points earned on unique critical thinking based, high Bloom's level problem scenarios designed for unit exams and based on the biological topics studied with the TBL. The use of TBL with case studies as the application exercise with an accompanying problem scenario assessment is a novel combination not found to date in research literature.

If our expectation is to move student thinking from knowledge memorization and recall to application, analysis, and synthesis (Bloom et al., 1956), the assessments must challenge students' understanding (Struyven, Dochy, Janssens, Schelfhou, & Gielen, 2006). Students prepare for examinations in ways that reflect how they believe they will be tested (Onwuegbuzie & Leech, 2003). The addition of the thought-provoking problem scenarios that required higher order thinking abilities on the part of students appears to be significant in increasing student content knowledge as illustrated by the results on the post-test scoring of questions. This is supported by an early review article that found in the opinion of business faculty, the 'case study or problem assignments' methods were effective in measuring student learning since they provided real-life cases (Michlitsch & Sidle, 2002).

Hypothesis 1: Content Knowledge Score Comparisons

One of the reasons for this study was to determine if student performance, as measured by scores on pre-test and post-test questions would be positively affected by TBL activities and the TBL-aligned assessment. Students in a course learn in different ways and at different rates. They also come from diverse educational and scientific backgrounds, and their knowledge and experience levels vary. The use of pre- and post-test experimental design was used in this research to determine whether a change resulted from the addition to exams of the new problem scenario assessment. The pretest, administered the first day of the semester, established a baseline of student's prior knowledge. This pretest measurement was administered to look for correlations between academic levels of knowledge of the students and to resolve discrepancies or factors that would influence learning and account for differences in the posttest results.

The pre-test mean score for the research semester of 2015 was similar to starting mean score percentages from prior semesters in the same course with the same instructor. Since course enrollments by students are random and no particular student was explicitly selected for this course, student baseline science knowledge measured by the pretest produced similar scores to previous semesters.

Prior research conducted with this course in 2014 resulted in no significant change in content knowledge when comparing pretest to posttest score gains (Agogo, 2015). In another study with introductory biology students that compared final exam scores between students in one section that were taught with TBL and in another section that were taught with traditional lecture format, no significant change was found (Carmichael, 2009). The students in that study had also taken a pre-semester exam and had virtually identical results, indicating a similar starting academic level as was experienced with this courses' research. TBL was the active learning method integrated in both introductory biology courses in the Carmichael and the Agogo studies with neither study resulting in significant gains in student scores at the end of the semester. In contrast, there has been research that resulted in improved individual exam performance where case studies were used as a learning tool. In one study, score improvements from first to last exam resulted (Bonney, 2015; Chaplin, 2009). Chaplin (2009) noted in a study that higher percentages of students in the case study section showed improvements on exams, and those same students did not experience as much of a decrease in scores when their exam scores declined as compared to the students from traditional lecture sections.

In the research study semester of the fall of 2015, the addition of the problem scenario assessments to supplement the TBLs and case studies did show significant results when examining specific TBL-aligned topic questions. When using case studies in the classroom, it is recommended to use case studies with tests (Herreid, 2015). The problem scenarios were mini-case designs that provided the problem solving type of assessment which stimulates higher order thinking and presents real-world situations. The addition of the problem scenarios to the unit exams in fall 2015 influenced the higher mean score percentage on questions related to osmosis, cellular respiration, and genetics when compared to fall 2014 student mean percentage scores on the same 15 questions.

Differences in scores may be attributed reuse of two of the TBLs with case study. Since the fall semester 2015 was the third semester the TBLs with case studies were conducted, a portion of the score improvements could be the result of content repetition in successive semesters and communications between students who completed the course previously. Other differences may have resulted from the introduction of one new TBL in the research semester and the addition of the three problem scenario assessments to unit exams in the fall 2015 research semester. Two of the same case studies regarding osmosis and genetics were used in the TBLs conducted during both fall semesters. One new TBL with case study that aligned to cellular respiration was introduced to the course in fall 2015. The problem scenario assessments were entirely new with fall 2015. No student had prior knowledge of the topic or format of the new assessment or the manner of solving the given problem. Each of the assessments, in the form of a scenario about one of the three biological TBL topics, required higher order thinking skills from the individual students in order to solve the problem and answer the questions correctly. This facilitation of in-depth thinking on the biological topics by students contributed to the increased post-exam scores that resulted in fall semester 2015.

The first hypothesis for this study predicted that TBL activities would positively affect student content knowledge for the specific case study aligned unit learning objective. Increased scores on the specific posttest questions aligned to osmosis, cellular respiration, and genetics results in significant *p*-values. The inclusion of the problem scenarios factored favorably as a contributor to the higher scores students achieved on the multiple-choice posttest targeted questions.

Hypothesis 2: Problem Scenario Short Essay Score Comparisons on Successive Exams

A second goal for this study was to show score improvements on successive short essays that students wrote as a response to the new problem scenarios incorporated into the course. As students became more familiar with how to read, evaluate, interpret, conclude, and formulate their answers to the problem scenarios, it was expected students would improve point scores. Most large university classes do not use short essay or writing assessments except in upper level or graduate capstone courses due to the need to score exams in a timely manner and consistency in scoring the written responses can be problematic. Herreid (2015) recommended incorporating case studies in tests for students when case studies are used as active learning in the classroom. (He does admit to having access to a large number of graduate students who can perform the grading.) He states that using the case method on exams forces students to solve real-world problems and moves them from memorization of facts. The problem scenarios for this research presented a mini-case for students. The problem scenarios themselves each had a slightly different design, which may have contributed to the differences in points achieved on the separate short essays.

The osmosis problem presented a scenario about a tubing product manufactured by a company providing supplies for dialysis to hospitals and medical offices. Students were given facts and details about substances, the permeability of the tubing, and the environment within and outside the tubing when in use. To solve the related questions asked, students had to determine information such as what substance would move across the membrane barrier and, if the substance moved, in what direction. Students were also given a word bank of 10 terms that they had to incorporate into their narrative and to use the terminology correctly. The terms given for this first problem scenario served as an aid to help students formulate their response.

The second problem scenario, related to cellular respiration, posed a different set of questions. The situation given was in regards to carbon monoxide and binding irreversibly to areas on the mitochondria where oxygen would normally bind. Students had to draw a mitochondria and its inner and outer membrane and show where oxygen, hydrogen, carbon monoxide, and the machinery to produce ATP were located. Students used arrows to indicate flow of molecules and ions across the mitochondrial membrane. They wrote their thoughts about the effect of carbon monoxide on ATP production and explained their reasoning. The point decreases, which resulted with responses to the second problem scenario, may be due to the carbon monoxide situation being too different from the TBL case study studied. The TBL case study concerned a weight loss drug and the fact that the drug caused a leaky mitochondrial membrane that prevented the build-up of a concentration gradient to drive the synthesis of ATP. In their responses, most students answered with a leaky membrane being the item affecting ATP production similar to the case studied in class. Students did not connect with the fact that oxygen, required to complete the production of ATP, could not be used since carbon monoxide was inhibiting the cycle. The disparity in the causes, which affected ATP production in the mitochondria between the two cases, may have resulted in the decline in points for the cellular respiration responses as compared to the higher osmosis points on the previous essay. Since the topic of cellular respiration was introduced as a new TBL and case study in fall 2015, this appeared to be a potential factor contributing to the lower short essay scores.

The third problem scenario, aligned to the study of genetics, was designed in three parts. Students had three cases to solve with each involving different genetic concepts: 1) two traits with complete dominance; 2) a test cross involving one trait with complete dominance; and 3) codominance. Each student was provided with Punnett squares to complete for each genetics case. They were required to complete the genotypes, describe the phenotypes and calculate probabilities, and write an explanation of their analysis.

All three problem scenarios had a slightly different format due to the complexity of the biological topic for which they were designed. Students demonstrated a good aptitude for solving each problem scenario although score increases on each successive short essay did not occur. When analyzing individual essay-to-essay scores for all students enrolled in the course, the comparisons from the osmosis to the genetics responses and the cellular respiration to genetics responses were both statistically significant increases.

Hypothesis 3: Pre and Posttest Mean Score Comparisons and Problem Scenario Short Essay Scores Comparison on Successive Exams by Science Background

Instead of between fall semester comparisons, for this third hypothesis, the analyses were performed only with the fall 2015 enrolled students. Since results were examined by students' self-reported science experience, it was anticipated that students who reported more science courses taken previously would score higher on pre and posttesting and also would score more points on short essay responses to the three problem scenarios. Pre and posttesting often separates students into groups for analysis since students who score higher on pretests may not realize gains as substantial as students who start with lower base knowledge (Marsden & Torgerson, 2012). ACT scores have also been used as a basis for assessing students' starting academic levels and correlate student performance gains to percentage of total exam points achieved (Chaplin, 2009).

The ANOVA tests performed comparing pretest-to-pretest scores showed surprising results. The students who self-reported for more science courses had a slightly lower starting mean score percentage than their less science peers. The smallest score improvements were between the posttest 15 targeted questions which was an interesting result. It was anticipated that the problem scenario assessments would trigger higher order thinking about the biological topics of the TBLs which would translate into the post-test 15 targeted questions yielding the greatest positive scores and largest gains. When comparing post-test to post-test scores from the 2014 fall control semester to the research semester for the 15 TBL targeted questions, higher scores were recorded in the 2015 fall semester and produced significant results. When comparing posttest-to-posttest student scores by self-reported science experience in the 2015 fall semester, no significant difference resulted between student scores. This was an interesting finding also supported by a study of introductory biology students in an active learning course section compared to a traditional lecture section who posted similar scores on a comprehensive final exam (Carmichael, 2009). While the students in the TBL with clickers section outperformed the lecture-based student section on all unit exams during the semester, the comprehensive final scores were fairly close in that study. One possible explanation for this result was TBL taught material may not have been retained long term as illustrated by the close student scoring on the comprehensive final.

The minimal difference in percentage gains between the science experience groups on 35 questions, which were not the subject of the TBL, and the greatest increase with the 15 targeted questions was expected. This also supports the hypothesis that the added focus and emphasis on these biological topics with thought-provoking problem scenarios resulted in more correct answers on the posttest and the greater increases noted.

An alternative expectation was that students with less science background might experience larger gains. The pretests, given before the course commenced, represented the student's knowledge coming into the course. From pre-test to post-test, the less science experienced students might potentially close the knowledge gap as compared to the more science-experienced students who were already operating at a higher thought level. Students with more science experience were expected to have a strong biological background to begin from consequently, their initial scores were higher. Although not analyzed for this study due the small percentages of males, it would interesting to analyze gender differences in performance. One STEM study examined case studies performance and perception by gender (Murray, 2016). Females reported enjoying case studies more than males and found them helpful in learning the topic. No differences in grade distributions and student performance based on gender were noted in the Murray study. The percentage of males enrolled in the Texas Woman's University course assessed was small; thus, no gender separation to study student performance by sex was viable. The fact that the courses are predominantly female though provides an excellent research study environment since retention of females in STEM professions is encouraged and desirable (Murray, 2016; PCAST, 2012).

Significance and Future Research Directions

The problem scenarios were designed to motivate and influence critical thinking skills. The grading of the short essays was performed normally during the semester and the grader had no knowledge of which science group the individual student would fall into when awarding points. The more science experienced students were expected to outperform their less science experienced peers since they were expected to possess a stronger science foundation. This proved to be the case. The minor difference in points between students with more science experience and students with less experience for the second short essays regarding cellular respiration was unexpected. The decrease in points coupled with the fact that this essay earned the lowest points value of all three essays indicated a lack of prior knowledge by all students about the topic prior to this course. It also indicates that the problem scenario presented was sufficiently different to the TBL case in class that students were unable to apply their new knowledge to solve the problem to the situation presented in the problem scenario.

The addition of problem scenarios to unit exams following a unit of study, which included a TBL with case study, resulted in increased scores by research semester students when comparing 2014 fall semester to 2015 fall semester post-test mean score percentages. The greatest score increases were achieved with questions on the posttest that specifically aligned to the biological topics, which were the subject of the new problem scenario assessments for this semester. Changes to classroom instruction such as the incorporation of writing assessments in this study contributed to higher content knowledge scores by students.

Future research with this course will focus on student profiling and integration of additional problem scenarios. Student profiling would include obtaining information about the student prior to taking to course and then correlating their background to the performance within the course. For this study, no gender analysis was conducted since the percentage of males enrolled in the course was small and no honors student breakout for analysis was possible due to a lack of permission to include their artifacts. Different variations of student profiles may provide information that would be useful in developing and implementing other active learning activities and assessments in the course.

Designing and integrating additional problem scenarios in exams, which measure student scores on specific biological topics not used with a TBL and case study activity, would help validate the results of this study. This implementation would help verify if the problem scenario assessment is the major contributor to the increase in post-test scoring or determine if the post-test question scores require the combination of the active learning strategies of TBL and problem scenario to be effective.

In the future, expanding the selection of biological topics to study with active learning methods will being examined. Course time limitations along with material and instructor resources may limit conducting TBL activities per unit of study. Adding another TBL activity with accompanying problem scenario or substituting in a different biological topic to determine if repetitive success can be achieved is under consideration.

The multiple choice questions on the pre and posttest, which were used as measures of student content knowledge improvements, could be re-written to increase their Bloom's difficulty ratings. However, the baseline pre-test mean score might change markedly as a result of this alteration. Another drawback to modifying the pretest questions would be the inability to use previous semester pre-test scores as a control for future research.

CHAPTER V

CONCLUSION

Educators seeking to comply with state requirements and show increases in student scores through end of semester testing may find this research useful. The research showed inclusion of topic specific problem scenarios to unit exams following TBL activities resulted in significant score increases on post-test questions related to the specific TBL-aligned biological topic. This increase in student content knowledge scores resulted from an increased emphasis on the topic through lecture and the TBL activities along with the individual student accountability for the material with the new assessment problems. The tangible results achieved from this research show that creating higher order thinking problems such as the specially designed scenarios can be a worthwhile commitment of time and resources to implement. With the requirement for accountability by state agencies for educational entities to show student score increases on standardized testing, the addition of thought provoking questions to exams given throughout the semester may prove effective in producing the desired student score improvements educators and higher education institutions are seeking.

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APPENDIX A

Osmosis Problem Scenario – Exam 2

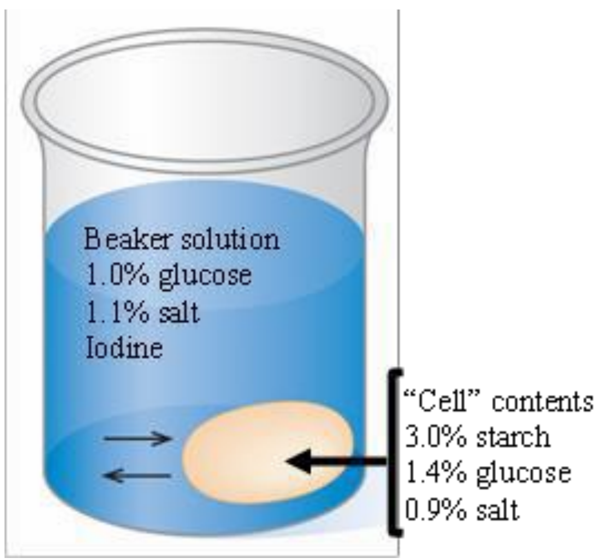
Essay Question (Value 10 points) You have been hired by a company named Tex-Dialytics International that is developing new plastics to be used in human kidney dialysis machines. You are given dialysis tubing representing a cell and have set up the following experiment.

The cell is filled with water and a mixture of 3% starch, 1.4% glucose, and 0.9% salt.

The cell is placed into a beaker containing water and 1.0% glucose and 1.1% salt. Iodine is also added to the beaker that the cell is immersed in. Iodine will react in the presence of starch and change color from yellow to blue-black.

The dialysis tubing is hypothesized to be permeable to glucose, salt, and iodine, but not permeable to starch. If this hypothesis is TRUE, what, if anything, will happen in this environment? Select one. Then answer the question on the following page.

a) cell will swell and cell contents turn blue-black
b) cell will shrink and cell contents turn blue-black
c) cell will swell and beaker solution will turn blue-black
d) cell will shrink and beaker solution will turn blue-black
e) cell will swell and no change will be detected in color within the beaker or the cell.



Explain your answer to your team supervisor by completing the ONE matching item below that matches your answer choice above. Write no more than 2 sentences. Use complete sentences with proper grammar, spelling, and punctuation. (Leave the other items blank.) Correctly use each of the following terms in your answer:
Water, salt, glucose, starch, iodine, osmosis, diffusion, selectively permeable, dialysis tubing, concentration gradient.

a) The cell will swell and contents will turn blue-black because: 1)

2)

b) The cell will shrink and contents will turn blue-black because: 1)

2)

c) The cell will swell and beaker solution will turn blue-black because: 1)

2)

d) The cell will shrink and beaker solution will turn blue-black because: 1)

2)

e) The cell will swell and no color changes are detected because: 1)

2)

APPENDIX B

Cellular Respiration Problem Scenario – Exam 3

46. The drug, DNP, which we studied in class, causes disruption of the electron transport chain in cellular respiration by eliminating the H+ (hydrogen) gradient within the mitochondrion. Cyanide poisoning also acts as a toxin and interferes with the normal functioning of the mitochondrion. Cyanide inhibits the electron transport chain by binding irreversibly to one of the proteins in the electron transport chain, cytochrome oxidase (an enzyme). One source of cyanide poisoning is house fires where products such as plastics, upholstery, and insulation may produce cyanide gas.

Given this: A patient is being treated for smoke inhalation she experienced during a house fire. Cyanide poisoning is suspected. Cyanide binds permanently to one of the proteins in the electron transport chain in the mitochondrion, disabling the electron transport chain function.

Decide this: What impact would cyanide poisoning have on ATP production? (Choose one answer.)

a. Reduces oxidative phosphorylation and ATP production
b. Increases oxidative phosphorylation and ATP production
c. There would no effect on ATP production

In the following section, make a drawing and write a brief narrative to support your answer to item 46. Refer to the grading rubric to be sure you have included the appropriate terms. <u>Draw a picture of the mitochondrion and explain what effect cyanide has on the electron transport and the production of ATP.</u>

Item	Use complete sentences and correct English grammar and punctuation. Include all of the following terms in your drawing and/or narrative: Oxidative phosphorylation (if appropriate) Substrate level phosphorylation (if appropriate) Electron transport chain ATP <u>Mitochondrial structures</u> including inner membrane, outer membrane, matrix, intermembrane space, electron transport chain, ATP synthase channel	Point Value
Drawing	Neat, clear, legible, and accurate. All items labeled correctly. If you use color for emphasis (encouraged), provide a key.	4 points
Explanation	Understanding of concepts is clearly demonstrated in narrative and diagram.	4 points

APPENDIX C

Genetics Problem Scenario – Final

91. Complete dominance, one character, using a test cross (4 points)

You have taken a part-time job at a dog kennel to earn a little extra money. Since you have just studied genetics in a college biology course, the kennel owner wants you to help her with a problem. In dogs, there is a hereditary deafness caused by a recessive gene, “d.” The kennel owner has a male dog she has named Bingo that she wants to use for breeding purposes if possible. The dog can hear, so the owner knows his genotype is either DD or Dd. If the dog’s genotype is Dd, the owner does not wish to use him for breeding so that the deafness gene will not be passed on. You remember studying “test crosses” in your biology course. You know that the question can be answered by breeding the dog to a deaf female (dd). Write a paragraph explaining your plan to the kennel owner. Include the following in your answer.

- Draw the two Punnett squares to illustrate these two possible crosses.
- In each case, what percentage of the offspring would be expected to be hearing? deaf?
- How could you tell the genotype of Bingo?
- Use complete sentences and proper English grammar in your answer.
- Use the following terms appropriately: test cross, homozygous, heterozygous, genotype, phenotype, offspring percentages appropriately in your answer.

92. Complete dominance, two characters (Value 3 points)

In humans, there is a gene that controls formation (or lack thereof) of muscles in the tongue that allow people with those muscles to roll their tongues, while people who lack those muscles cannot roll their tongues. The ability to roll one's tongue is dominant over non-rolling. The ability to taste certain substances is also genetically controlled. For example, there is a substance called phenylthiocarbamate (PTC for short), which some people can taste (the dominant trait), while others cannot (the recessive trait). The biological supply companies actually sell a special kind of tissue paper impregnated with PTC so students studying genetics can try tasting it to see if they are tasters or non-tasters. To people who are tasters, the paper tastes very bitter, but to non-tasters, it just tastes like paper. Let's let **R** represent tongue-rolling, **r** represent a non-roller, **T** represent ability to taste PTC, and **t** represent non-tasting.

Suppose a woman who is both a homozygous tongue-roller and a non-PTC-taster marries a man who is a heterozygous tongue-roller and is a PTC taster, and they have three children: a homozygous tongue-roller who is also a PTC taster, a heterozygous tongue-roller who is also a taster, and a heterozygous tongue-roller who is a non-taster.

- What is the genotype of the mom?
- What is the genotype of the dad?
- Show the crosses using Punnett squares for this mom and dad in the space below
- What is the probability that their children will be a non-tasters who is homozygous for tongue rolling?
- Use complete sentences and proper English grammar in your answer.
- Use the following terms appropriately: homozygous, heterozygous, genotype, phenotype, offspring percentages appropriately in your answer.
- Be sure that your logic and conclusions are clearly stated.

93. Codominance (Value 3 points)
Mothers #1, #2, and #3 all entered the hospital and delivered babies on the same day. The babies were taken to the hospital nursery for care. The parents later claimed that the babies had been mixed up in the hospital. As the hospital administrator, it is your job to determine which baby rightfully belongs to each set of parents. You have all parents and babies blood types tested. The results of the ABO blood typing are listed below.

- Explain which baby you matched with each set of parents and why.
- Give evidence in the form of Punnett squares for each set of parents.
- Use the following terms appropriately: homozygous, heterozygous, genotype, phenotype, offspring percentages appropriately in your answer.
- Explain your answer in complete sentences using proper English grammar.
  - Be sure your logic is clear and your answer is complete. Mother #1 = type A, Father #1 = type B

Mother #2 = type B, Father #2 = type O Mother #3 = type A, Father #3 = type A
Baby X = type O, Baby Y = type AB, Baby Z = type B

APPENDIX D

Osmosis Problem Scenario Grading Rubric – Exam 2

These are rather long, compound sentences but include all 10 terms as an example. The response is broken into the 2 parts of the answer choice into 2 sentences where 1 sentence explains what happens to the cell and 1 sentence is related to any color change.

1) *The cell will swell because*
the dialysis tubing represents a selectively permeable membrane (controls molecule movement in or out) which allows water via osmosis (movement of water across a selectively permeable membrane) and salt via diffusion to move down their respective concentration gradients (from high to low concentration) from the beaker solution into the cell while glucose molecules will use diffusion to exit the cell.

2) *The contents will turn blue-black because:*
iodine will use diffusion to move down its concentration gradient from the beaker solution into the cell where, in the presence of starch, iodine reacts to turn a blue-black color and, since the starch cannot diffuse from the cell (non-permeable), the beaker solution remains yellow.

Rubric:
2.0 points for correct multiple choice answer

MULTIPLE CHOICE: TOTAL 2 POINTS
2.0 points for using all 10 terms (.20 each x 10 = 2.0 (even if they selected an incorrect choice but were able to place the terms in cohesive sentences)
3 points for each sentence when MC answer is correct and max 2 points each when MC answer choice was incorrect but terms usage/description is correctly used:
The sentences must accurately explain the terms, usage, and student must write a correct sentence describing the “because” statement they chose.

WRITTEN SECTION: TOTAL 8 POINTS (4 POINTS max for wrong choice but good explanation of terms)

RUBRIC for OSMOSIS PROBLEM SOLVING/CRITICAL THINKING – Exam 2 – FALL 2015 BIOL 1113		
Student Selected Correct Multiple Choice Answer		Max.
Yes		8 points
No (divide points earned by ½?)		4 points
Sentences (2) must contain the following correct thinking:		Points
COMPOSITION/CORRECT TERMINOLOGY USAGE/ACCURATELY DESCRIBES (Bloom's Taxonomy 5-Synthesis)		
alysis Tubing (represents a cell) is Selectively Permeable Describes: controls/allows substances/molecules move in/out of cell	1.0	
Concentration Gradient: molecules move from where they are in high concentration/abundance to where they are in low concentration/abundance	0.75	
MOLECULAR MOVEMENT (non-Water) (Bloom's Taxonomy 6-Evaluate)		
How Molecules (other than water) Moved (or did not move)? ffusion of Molecules (list each movement/direction and in/out of cell): Student needs to have stated these molecules are moving by diffusion and whether entering or exiting the cell or, conversely, entering or exiting the beaker solution		
Glucose exits cell via diffusion	0.75	
Salt enters cell via diffusion	0.75	
Iodine enters cell via diffusion	0.75	
Failure to indicate the above molecules move by diffusion (each occurrence)	-0.25	
Starch does not move (no movement/no diffusion – non-permeable)	0.5	
Starch reacts with Iodine (cell contents turn blue-black)	0.75	
MOLECULAR MOVEMENT (Water) (Bloom's Taxonomy 6-Evaluate)		
How Water Molecules Moved? Osmosis: movement of water via its concentration gradient across a selectively permeable membrane Student needs to have stated movement of water is by osmosis and which way the osmosis (water movement) occurred – in or out of cell		
Water enters cell by osmosis (cell swells)	0.75	
Failure to indicate water moves by osmosis	-0.25	
SUBTOTAL SENTENCES		6.0

USED ALL TERMS IN COHESIVE THOUGHT SENTENCES (Bloom's Taxonomy 4-Analyze, 5-Synthesis)			.20 each		
		Salt		.20	
		Starch		.20	
		Glucose		.20	
		Iodine		.20	
		Water		.20	
		Diffusion		.20	
		Osmosis		.20	
		Concentration Gradient		.20	
		Dialysis Tubing		.20	
		Selectively Permeable		.20	
				SUBTOTAL TERMS	2.0
		TOTAL POINTS			8.0

BIOLOGY 1113 Exam 2 KEY
The written section for Exam 2 is worth up to 8 points.
2.0 points for using all 10 required terms when the concept was described correctly in the sentence. The remaining 6 points were earned when accurately describing first, what caused the cell to swell and second, whether the solution in the cell or beaker turned color and why.
The sentences must accurately explain the terms, usage, and student must write a correct sentence describing the "because" statement they chose.

The short essay (sentences) were scored based on understanding, describing, and using the following terms correctly in sentences:
Key concept: Selectively permeable – the membrane controls which molecules can pass; only allows specific molecules to enter or exit
The dialysis tubing represented a cell with a membrane that is <u>selectively permeable</u>.
Membranes can also be: Freely permeable meaning all molecules can pass through the membrane (same as no membrane being present) or Non-permeable meaning the membrane will not allow specific molecules (or all molecules) to pass from the side they are on regardless of concentration level
Key concept: Concentration Gradient – Molecules will pass through a permeable membrane from where they are in high concentration to where they are in low concentration
Key concept: Diffusion – molecules will diffuse or scatter from where they are in high concentration to where they are in low concentration
Key concept: Osmosis – diffusion of Water through a selectively permeable membrane; from the side of the membrane where water is in higher concentration to the side of the membrane where water is in lower concentration
Molecules are constantly in motion and collide with each other to scatter; molecules will move from an area of greater abundance to an area of lesser abundance. IF a membrane is present, the movement of molecules will depend on the permeability of the membrane; the gradient refers to the movement "down" from High to Low concentration

Key concept: Reaction of Iodine with Starch – iodine is a test indicator for starch molecules and changes color from yellow to blue-black when exposed to starch

Information given in the statement problem:

The salt, glucose, and iodine are permeable. They will pass through the membrane of the cell VIA DIFFUSION based on their concentrations: SALT DIFFUSES INTO THE CELL (more concentration in the beaker solution); GLUCOSE DIFFUSES FROM THE CELL (more concentration in the cell); IODINE DIFFUSES INTO THE CELL (concentration high in the beaker solution; none in the cell).

Starch is impermeable (the membrane will not allow this molecule to pass). STARCH WILL NOT DIFFUSE from the cell.

WATER ENTERS THE CELL VIA OSMOSIS since there is more water in the beaker solution and less in the cell so THE CELL SWELLS. (More total solute in the cell so less water.)

IODINE that diffused into the cell DETECTS THE STARCH and REACTS to TURN BLUE-BLACK.

****

1) The cell will swell because

the dialysis tubing[1] represents a selectively permeable membrane[2] (controls which molecules can pass) which allows water[3] via osmosis[4] (movement of water across a selectively permeable membrane) and salt[5] via diffusion[6] to move down their respective concentration gradients[7] (from high to low concentration) from the beaker solution into the cell while glucose[8] molecules will follow their concentration gradients and use diffusion to exit the cell.

2) The contents will turn blue-black because:

iodine[9] will use diffusion to move down its concentration gradient from the beaker solution into the cell where, in the presence of starch[10], iodine reacts to turn a blue-black color and, since the starch cannot diffuse from the cell (non-permeable), the beaker solution remains yellow.

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In the above sentences, all 10 terms were used and describe correctly the activity and movement of the various molecules based on their ability to permeate (pass) through the membrane.

APPENDIX E

Cellular Respiration Problem Scenario Grading Rubric – Exam 3

RUBRIC for CYANIDE POISONING PROBLEM SOLVING/CRITICAL THINKING – Exam 3 – FALL 2015 BIOL 1113		
Diagram of Mitochondrion		4 points
Narrative: Explanation of Cyanide Poisoning		4 points
MITOCHONDRION DRAWING and CORRECT LABELING No points are deducted for membranes without phospholipid bilayer (2 layers) (Bloom's Taxonomy 4-Analysis)		4 points TOTAL
Outer Membrane (bilayer however single line acceptable)	0.5	
Inner Membrane (bilayer however single line acceptable)	0.5	
Intermembrane Space – between outer and inner membrane	0.5	
Matrix – area inside inner membrane – may show cristae (folds of inner membrane)	0.5	
Electron Transport Chain – drawn inserted in inner membrane – ID and Label	0.5	
ATP Synthase Channel – drawn inserted in inner membrane – ID and Label	0.5	
ETC – NADH and FADH2 (products of substrate level phosphorylation) contributes hydrogen ions (protons) and electrons. Electrons flow through complexes located in the inner membrane with energy release at each complex that provides energy to pump protons (hydrogen ions) into intermembrane space and establishes the proton gradient. Final electron acceptor results in water. Diagram includes arrows with H+ (protons) heading to intermembrane space or narrative describes this action	0.5	
ATP Synthase Channel – Many copies of this protein complex exist in the inner membrane of the mitochondrion. Protons (hydrogen ions that have been pumped into the intermembrane space) can only enter through this channel. Proton motion down the concentration gradient causes ATP production by phosphorylating ADP (from ADP + inorganic phosphate by the ATP Synthase (enzyme). Diagram includes arrows with H+ (protons) movement from intermembrane space to the matrix through ATP Synthase channel which causes inorganic phosphate to bond to ADP producing ATP or narrative describes this action	0.5	

NARRATIVE OF THE EFFECT OF CYANIDE POISON		4 points TOTAL
Describe how cyanide has affected the ETC (Bloom's Taxonomy 5-Synthesis, 6-Evaluation):	1.0 TTL	
The binding of cyanide disrupts the movement of electrons as they flow from higher to lower energy states down the ETC (See how ETC works) Cyanide is an INHIBITOR not an un-coupler like DNP	0.5	
Cyanide causes the body's ATP production overall to be REDUCED (combination of aerobic and anaerobic respiration) (See ATP Synthase Channel and Proton Gradient)	0.5	
EXTRA: AEROBIC ATP production ends/ceases/stops due to cyanide – Cyanide prevents the final pair of electrons from forming water with oxygen. Oxygen is the final electron acceptor in the ETC (oxygen captures the electrons at the low end of the chain and along with hydrogen forms water). Cyanide has bound to the enzyme so oxygen cannot bind. ETC stopped. Too high a proton gradient, electrons will not move through the ETC.	+0.5	
EXTRA: Person is unable to use oxygen; cyanide bound irreversibly. Blood returns to heart still oxygenated – person may turn bright red "cherry" skin color similar to carbon monoxide poisoning. Person still breathes normally but oxygen is not being used. Person eventually dies.	+0.5	
EXTRA: ANAEROBIC ATP production continues until too much pyruvate builds up and is converted to lactic acid – person dies or may have already from binding of cyanide and not enough ATP overall could keep them alive	+0.5	
ETC ROLE IN CELLULAR RESPIRATION – HOW IT WORKS: ETC major function is to establish and maintain the proton gradient (compare matrix to intermembrane space – higher concentration in intermembrane space due to pumping of protons driven by electron movement down the transport chain (Bloom's Taxonomy 5-Synthesis, 6-Evaluate)	1.0 TTL	
NADH and FADH2 electron carriers (products from Glycolysis and Krebs) are in matrix of mitochondrion. These	0.25	

carriers reduce giving up electrons and protons (hydrogen ions) Example: NADH > $NAD^+ + H^+ + 2e^-$ Electrons pass along the ETC (complexes in inner membrane) and release energy at each step (through the protein enzyme complexes) in the chain which drives the pumping of H+ (protons) into the intermembrane space The hydrogens (H^+ or protons) pumped out into the intermembrane space establish the proton gradient (driven by energy released as electrons move down the chain. Electrons moving from higher energy states to lower energy states at each movement through the ETC) Hydrogen ions (protons) in the intermembrane space (proton gradient) want to more down their concentration gradient and cross back through the inner membrane into the matrix however inner membrane is impermeable to them. Hydrogen ions can only pass through ATP Synthase Channel. Proton motion causes rotor/motor function for energy transfer to produce ATP (ADP and inorganic phosphate combine to generate ATP)	0.25 0.25 0.25	
EXTRA: Intermembrane space becomes more acidic from hydrogen ions and matrix becomes more basic	+0.5	
Oxidative Phosphorylation: (Bloom's Taxonomy 5-Synthesis, 6-Evaluate)		
Occurs during ETC and chemiosmosis (ATP Synthase channel). Thousands of copies of the ETC exist in each mitochondrion. The power source for oxidative phosphorylation (producing ATP from ADP and P*i* comes from the redox reactions of the ETC. ATP Synthase uses oxygen and power from proton motion.	1.0	
Substrate Phosphorylation: (Bloom's Taxonomy 5-Synthesis, 6-Evaluate)		
ATP formation occurs when phosphate group is removed from a substrate molecule and bound to ADP. Occurs during glycolysis and Krebs (citric acid) Cycle when series of enzymes bind to specific substrates. This metabolic pathway releases CO2, small amount of ATP from substrate level phosphorylation of ADP, high energy products NADH and FADH2 (electron carriers) head to the ETC.	1.0	
EXTRA: Chemiosmosis Theory: Energy stored in	+0.5	

hydrogen concentration gradient (higher in intermembrane space) flows to drive synthesis of ATP		
TOTAL POINTS TO EARN: 4 points Diagram / 4 points Narrative EXTRA CREDIT POINTS: Up to 2.5 points possible		8.0

PROBLEM AS WRITTEN:
The drug, DNP, which we studied in class, causes disruption of the electron transport chain in cellular respiration by eliminating the H+ (hydrogen) gradient within the mitochondrion. Cyanide poisoning also acts as a toxin and interferes with the normal functioning of the mitochondrion. Cyanide inhibits the electron transport chain by binding irreversibly to one of the proteins in the electron transport chain, cytochrome oxidase (an enzyme). One source of cyanide poisoning is house fires where products such as plastics, upholstery, and insulation may produce cyanide gas.

GIVEN:

A patient is being treated for smoke inhalation she experienced during a house fire. Cyanide poisoning is suspected. Cyanide binds permanently to one of the proteins in the electron transport chain in the mitochondrion, disabling the electron transport chain function.

DECIDE:

What impact would cyanide poisoning have on ATP production?

a. Reduces oxidative phosphorylation and ATP production
b. Increases oxidative phosphorylation and ATP production
c. There would be no effect on ATP production.

Make a drawing and write a brief narrative to support your answer.
Drawing to include: outer membrane, intermembrane space, inner membrane with electron transport chain and ATP synthase channel embedded, surrounding matrix with NADH/FADH2 and ATP in interior and H+ (protons)
Narrative to include

CYANIDE will REDUCE oxidative phosphorylation and ATP production because:

Cyanide binds irreversibly to the enzyme cytochrome oxidase inhibiting its function. (Enzymes are specific to the substrate, in this case, oxygen cytochrome oxidase. Cyanide binding changes the shape of the protein and it denatures or no longer

functions.) Oxygen is the final electron acceptor in the ETC and, along with hydrogen, produces water as the final step. Since the final pair of electrons cannot be transferred, ETC stops. Phosphorylating ADP requires oxygen and the inability to use oxygen also adversely affects the ATP Synthase channel which cannot produce ATP aerobically.
Since the majority of ATP is produced aerobically, anaerobic ATP production via glycolysis may occur but not enough ATP is produced to sustain life.
Narrative examined for:

- No other substrate can bind to the protein complex and ETS halts
- Oxidative Phosphorylation via the ATP Synthase Channel cannot occur; No ATP Synthase action, no ATP
- ANEROBIC ATP production may continue but is not enough energy to sustain brain and heart – person lapses into a coma and eventually dies
- Cyanide binds tightly so that it cannot transport any electrons to oxygen. This blocks the further passage of electrons throughout the chain halting the ETC operation. Protons cannot pass back into the matrix of the mitochondria, thus, the concentration of protons build up in the intermembrane space and the gradient becomes large. The person is deprived of chemical energy to perform the many numerous processes that sustain life and the person dies.
- Body does not use oxygen even though person is breathing normally. Blood continues to be oxygenated but not used so circulates oxygenated. Persons who suffer from cyanide poisoning may exhibit a “cherry” color to the skin from the oxygenated blood.
- The electron transport chain **does not** make ATP directly. Cyanide blocks electron flow to oxygen.
- The final stage of cellular respiration is the electron transport chain (ETC). The ETC is a series of molecules embedded in the inner mitochondrial membrane. The first molecule accepts protons and electrons from the products of substrate level phosphorylation, namely, glycolysis and the Krebs Cycle: NADH and FADH2. The electrons carried by these molecules are passed along the complexes within the ETC and finally react with oxygen and protons to form water. Without oxygen, the final reaction cannot occur. This causes a ‘traffic jam’ in that electrons further back on the chain as they cannot be transferred. The entire process stops. In the absence of oxygen, the ETC stops working and no ATP is generated. Cyanide prevents oxygen from binding to the final molecule in the electron transport chain. Individuals poisoned with cyanide die from oxygen deprivation even though their cells may have abundant oxygen.

APPENDIX F

Genetics Problem Scenarios Grading Rubric – Final

CASE 1: Q91 Complete dominance, one character, using a test cross (4 points)
You have taken a part-time job at a dog kennel to earn a little extra money. Since you have just studied genetics in a college biology course, the kennel owner wants you to help her with a problem. In dogs, there is a hereditary deafness caused by a recessive gene, “d.” The kennel owner has a male dog she has named Bingo that she wants to use for breeding purposes if possible. The dog can hear, so the owner knows his genotype is either DD or Dd. If the dog’s genotype is Dd, the owner does not wish to use him for breeding so that the deafness gene will not be passed on. You remember studying “test crosses” in your biology course. You know that the question can be answered by breeding the dog to a deaf female (dd). Write a paragraph explaining your plan to the kennel owner. Include the following in your answer.

- Draw the two Punnett squares to illustrate these two possible crosses.
- In each case, what percentage of the offspring would be expected to be hearing? deaf?
- How could you tell the genotype of Bingo?
- Use complete sentences and proper English grammar in your answer.
- Use the following terms appropriately: test cross, homozygous, heterozygous, genotype, phenotype, offspring percentages appropriately in your answer.

Bingo >> Female Deaf V recessive V	D	D
d	Dd	Dd
d	Dd	Dd

Bingo >> Female Deaf V recessive V	D	d
d	Dd	dd
d	Dd	dd

The genotype of Bingo can be determined by using a test cross with a known recessive genotype female. Since deafness, the expressed phenotype, is homozygous recessive (dd), breeding Bingo with this female will either result in offspring that can all hear (heterozygous Dd) if Bingo is dominant homozygous DD or in ½ hearing and ½ deaf if Bingo is heterozygous Dd. Bingo should not be considered for breeding if any offspring from the test cross are deaf.

RUBRIC for GENETICS PROBLEM SOLVING/CRITICAL THINKING – Exam Final – FALL 2015 BIOL 1113		
Maximum Points:		4 points
Sentences must contain the following correct thinking:		Points
PUNNETT SQUARE Drawing and Labeling: Bloom's Taxonomy 4-Analysis)		2.0
A Square: DD x dd = Dd offspring	0.50	
B Square: Dd x dd = ½ Dd and ½ dd	0.50	
Offspring percentages? 100% Dd offspring, all hearing	0.50	
Offspring percentages? 50% Dd = hearing, 50% dd = deaf	0.50	
How could you tell the genotype of Bingo?		1.0
Test cross – simple method for discovering the genotype of a dominant expressing phenotype organism with unknown genotype (*XX or Xx); is* bred with recessive phenotype with known homozygous (*xx) recessive* genotype	0.5	
Your plan and expected results to kennel owner on viability of Bingo for breeding	0.5	
Terminology used correctly in explanation of Bingo's desirability for breeding? (Bloom's Taxonomy 5-Synthesize)		1.0
Homozygous, heterozygous	0.5	
Genotype, phenotype	0.5	
TOTAL DRAWINGS AND CALCULATION		4.0

CASE 2: Q92 Complete dominance, two characters (3 points)
In humans, there is a gene that controls formation (or lack thereof) of muscles in the tongue that allow people with those muscles to roll their tongues, while people who lack those muscles cannot roll their tongues. The ability to roll one's tongue is dominant over non-rolling. The ability to taste certain substances is also genetically controlled. For example, there is a substance called phenylthiocarbamate (PTC for short), which some people can taste (the dominant trait), while others cannot (the recessive trait). The biological supply companies actually sell a special kind of tissue paper impregnated with PTC so students studying genetics can try tasting it to see if they are tasters or non-tasters. To people who are tasters, the paper tastes very bitter, but to non-tasters, it just tastes like paper. Let's let **R** represent tongue-rolling, **r** represent a non-roller, **T** represent ability to taste PTC, and **t** represent non-tasting.
Suppose a woman who is both a homozygous tongue-roller and a non-PTC-taster marries a man who is a heterozygous tongue-roller and is a PTC taster, and they have three children: a homozygous tongue-roller who is also a PTC taster, a heterozygous tongue-roller who is also a taster, and a heterozygous tongue-roller who is a non-taster.

- What is the genotype of the mom?
- What is the genotype of the dad?
- Show the crosses using Punnett squares for this mom and dad in the space below
- What is the probability that their children will be a non-tasters who is homozygous for tongue rolling?
- Use complete sentences and proper English grammar in your answer.
- Use the following terms appropriately: homozygous, heterozygous, genotype, phenotype, offspring percentages appropriately in your answer.
- Be sure that your logic and conclusions are clearly stated.

Mom >> Tongue-roller V Dad V	R	R
R	RR	RR
r	Rr	Rr

Mom >> Non-PTC taster V Dad V	t	t
T	Tt	Tt
t	tt	tt

While tongue rolling and PTC tasting are independent genes, all offspring will express the phenotype of tongue rolling with dominant genotypes of either RR or Rr. ½ or 50% will have homozygous genotype for tongue rolling. ½ of offspring will have a heterozygous genotype for PTC tasting (Tt) and ½ of offspring will have a recessive homozygous genotype (tt) with non-PTC tasting phenotypes. While tongue rolling and PTC tasting are independent genes, the probabilities of each separate event occurring at the same time is determined by multiplying the fractions together. Calculate the # of offspring who are tongue rollers with homozygous genotype RR by the # of offspring non-PTC tasters. ½ x ½ = ¼ or 25% will express phenotypes of tongue rolling and have homozygous genotypes RR and express non-PTC tasting with recessive tt genotype.

RUBRIC for GENETICS PROBLEM SOLVING/CRITICAL THINKING – Exam Final – FALL 2015 BIOL 1113		
Maximum Points:		4 points
Sentences must contain the following correct thinking:		Points
PUNNETT SQUARE Drawing and Labeling: (Bloom's Taxonomy 4-Analysis)		1.50
A Square: Tongue rolling RR (given: homozygous) x Rr (given: heterozygous) = RR or Rr offspring all expressing dominant tongue rolling characteristics	0.25	
B Square: Mom non-PTC taster tt x Tt Dad PTC taster Dad could be homo- or heterozygous for tasting. Since 1 of the children is a non-PTC tasting child (recessive), Dad must be heterozygous Tt	0.25 0.25	
What is the genotype of the mom? RRtt	0.25	
What is the genotype of the dad? RrTt	0.25	
Offspring percentages? 50% or ½ with be tongue rollers with genotype RR Offspring percentages? 50% Tt = PTC taster; 50% tt = non-PTC taster	0.25	
What is the probability that their children will be a non-PTC taster who is homozygous for tongue rolling? (Bloom's Taxonomy 5-Synthesize, 6-Evaluation)		1.50
Probability calculation	0.5	
Homozygous, heterozygous	0.5	
Genotype, phenotype	0.5	
TOTAL DRAWINGS AND CALCULATION		3.0

CASE 3: Q93. Codominance (3 points)

Mothers #1, #2, and #3 all entered the hospital and delivered babies on the same day. The babies were taken to the hospital nursery for care. The parents later claimed that the babies had been mixed up in the hospital. As the hospital administrator, it is your job to determine which baby rightfully belongs to each set of parents. You have all parents and babies blood types tested. The results of the ABO blood typing are listed below.

- Explain which baby you matched with each set of parents and why.
- Give evidence in the form of Punnett squares for each set of parents.
- Use the following terms appropriately: homozygous, heterozygous, genotype, phenotype, offspring percentages appropriately in your answer.
- Explain your answer in complete sentences using proper English grammar.
  - Be sure your logic is clear and your answer is complete. Mother #1 = type A, Father #1 = type B

Mother #2 = type B, Father #2 = type O Mother #3 = type A, Father #3 = type A

Baby X = type O, Baby Y = type AB, Baby Z = type B

#1 Mom > Father	A	A or O
B	AB	AB or BO
B or O	AB or AO	AB, AO, BO or OO

#2 Mom > Father	B	B or O
O	BO	BO or OO
O	BO	BO or OO

#3 Mom > Father	A	A or O
A	AA	AA or AO
A or O	AA or AO	AA/AO or OO

The ABO blood groups are examples of multiple alleles of a gene. A blood type A individual may be homozygous AA or heterozygous AO genotypes and the same with blood type B individual with BB or BO genotypes. An individual with O blood types is homozygous OO genotypes since O blood is a recessive allele. If we assume that all parents are homozygous genotypes, the offspring percentages are: 100% AB for Family #1 with blood type AB, 100% BO for Family #2 with blood type B, and 100% AA for Family #3 with blood type A. Therefore, the only known genotype for the parents is Dad #2 who is homozygous OO genotype and expressed O phenotype in blood. All other mothers and fathers are either homozygous AA or BB or heterozygous AO or BO. By examining the possible genotypes created by the Punnett squares, it follows that Baby Y must belong to Family #1. This is the only couple with a genotype of AB possible in their offspring. While this family could have children of all 4 blood phenotypes, no other couples could produce an AB blood type. This logic also follows for assigning Baby Z to Family #2. Family #2 could produce children with B or O blood types while Family #3 could produce children with A or O. Baby Z with a B phenotype when tested would be heterozygous BO genotype since the father is a recessive homozygous OO genotype for blood. Lastly, the OO Baby X belongs to Family #3 who can produce AA, AO, or OO genotypes for A or O phenotype blood.

RUBRIC for GENETICS PROBLEM SOLVING/CRITICAL THINKING – Exam Final – FALL 2015 BIOL 1113		
Maximum Points:		4 points
Sentences must contain the following correct thinking:		Points
PUNNETT SQUARE Drawing and Labeling: (Bloom's Taxonomy 4-Analyze)		1.50
#1 Family Square: AA/AO x BB/BO = AB as 1 possibility; all 4 blood types possible	0.25	
#2 Family Square: BB/BO x OO = B or O blood type offspring	0.25	
#3 Family Square: AA/AO x AA/AO = A or O blood type offspring	0.25	
(Points were given even if all possible combinations were not presented)		
Family #1 = Baby Y (AB); Family #2 = Baby Z (B); Family #3 = Baby X (O)	0.75	(.25 each)
Explanation of how you matched parents and babies Terminology used correctly in explanation (Bloom's Taxonomy 5-Synthesize, 6-Evaluation)		1.50
Baby matching explanation	1.0	
Homozygous, heterozygous	0.25	
Genotype, phenotype	0.25	
TOTAL DRAWINGS AND CALCULATION		3.0