THE EFFECTIVENESS OF HYBRID PROBLEM-BASED LEARNING VERSUS MANUAL-BASED LEARNING IN THE MICROBIOLOGY LABORATORY

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Promising results from the use of problem-based learning (PBL) as a teaching method in medical programs have encouraged many institutions to incorporate PBL into their curricula. This study investigates how applying hybrid-PBL (H-PBL) in a microbiology laboratory impacts students’ higher-order thinking as compared to applying a lecture-based pedagogy. The experimental design compared the learning outcomes of two groups of students: the control group and the H-PBL group, for whom PBL cases comprised 30% of the curriculum. Both groups were taught basic skills for the microbiology lab by the same instructor. Using the traditional teaching style for the control group, the instructor offered each student what they needed for their experiments. The H-PBL group practiced experimental design, data analysis, theory proposal, and created research questions by using six study cases that were closely linked to the area of study. The outcome was measured using a pre- and post-assessment consisting of 24 questions that was designed by following Bloom’s taxonomy of learning levels. A one-way ANOVA was used to analyze the data. The results showed that for the first three levels of Bloom’s taxonomy—knowledge, comprehension, and application—there were no statistically significant differences between the H-PBL and control group gain scores as determined by a one-way ANOVA. For the knowledge level, $f(1, 78) = .232$, and $p = .632$; for the comprehension level, $f(1, 78) = .004$, and $p = .951$; and for the application level $f(1, 78) = .028$, and $p = .863$. On the other hand, the gain scores for the three higher levels—analysis, evaluation, and creativity—improved for the H-PBL group. The analysis level showed statistically significant differences, with $f(1, 78) = 4.012$, and $p = .049$. Also, there were statistically significant
differences in students’ performance at the evaluation level, with $f(1, 78) = 11.495$, and $p = .001$, and the creativity level, with $f(1,78) = 23.432$, and $p = .000$. In conclusion, the study results supported the value of incorporating hybrid problem-based learning (H-PBL) into the traditional microbiology laboratory curriculum.
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CHAPTER 1
INTRODUCTION

*Learning science is something students do, not something that is done to them.*

National Research Center

1.1 The Importance of Lab Experiments

According to Lunetta et al. (2007, p. 394), the laboratory section of science classes in the 19th and 20th century consisted of a “learning experience in which students interact with material or with secondary sources of data to observe and understand the natural world”. In fact, laboratory activities make up a critical part of science (Hofstein & Lunetta, 2004). Most information in biology, biochemistry, physics, and organic chemistry is derived from the laboratory (Uden & Beaumont, 2006). In this practical environment, students utilize tools, equipment, chemical reagents and living organisms to gather data and test hypotheses (Psillos & Niedderer, 2002). In doing so, students can bring knowledge to life through observations of hands-on experiments.

In the field of science education, it was long ago noted that the laboratory sections of many courses bring the natural world close in order to help students to understand it, and that the theoretical lecture may fall apart without practical experiments supporting it (Edgeworth & Edgeworth, 1811, cited by Rosen, 1954). Further, numerous studies note that the involvement of laboratory experiments in certain subjects leads students to have a more positive disposition toward science (Hofestien & Lunetta, 2004, 1982; Bate, 1978). According to Hofstein et al. (2013, 1976), when students rated the value of the laboratory section in comparison to the other elements of a chemistry class, the laboratory stood at the top of the ratings. In another study, a
curriculum that included time doing hands-on projects motivated students to enroll in advanced chemistry, an elective high school course (Milner et al., 1987, cited by Gabel, 1994).

1.2 The Purpose of School Laboratories

According to Gabel (1994) and colleagues (Bennett & O’Neale, 1998; Garratt, 1997; Gunstone & Champagne, 1990), the laboratory facilitates achievement of the following key objectives:

- An understanding of how science is accomplished and how scientists work
- The learning of practical and metacognitive skills (problem solving, data analysis, and reasoning skills)
- Knowledge gain with respect to methods of scientific inquiry
- The encouragement of cooperative learning
- Increased motivation and interest in science for students
- Experience in acquiring, manipulating and processing data
- Improved observational, recording, and presentation skills

1.3 Traditional Labs

Traditionally, labs are often taught using a “cookbook” format (Domin, 1999, p. 543), or as a “recipe lab” (Hackling, 2005, p. 3), in which students are given step-by-step protocols for an experiment with anticipated results. In such cases, it is not necessary to think deeply about the experiments to be successful (Sleet et al., 1994). Moreover, limited opportunities remain for interpretation or analysis of the data (Johnstone, 1997). In addition, traditional labs in such cases ignore the application of scientific concepts to deal with experiments (Selcuk, 2010), putting
students in a passive position where they are not given the opportunity to make decisions (Hackling, 2005).

A close examination of how school-based laboratories have been conducted over the years, clearly reveals the mismatch between the outcomes of these labs and their original goals, as given by Gabel et al. (1994) and listed above in section 1.2 (Hofstein & Lunetta, 1982; Bate, 1978). Weiss et al. (2003) claimed that 59% of mathematics and science courses encourage passive learning and focus on memorization, instead of placing a greater emphasis on understanding.

Although the laboratory is a good place to practice natural world experiments, giving students predesigned experiments limits their ability to explore the real science behind the natural world (Selcuk, 2010). Furthermore, when students have a ‘cookbook’ with all of the required protocols detailed, they do not need to use high-level skills in their lab work (Tamir & Lunetta, 1981), and this may turn them into technicians rather than scientists. In fact, the manner in which traditional laboratories are usually handled is inconsistent with several recommendations from diverse studies. For example, Bruner (1996, p. 85) claimed that the best way for college students to learn science is to “construct meanings rather than just receiving them”. The National Science Education Standards (2010) also clearly indicate this, stating “education should reflect the way science is done” (p. 9) and “students learn best by active participation in the learning process.” In the traditional laboratory it is rare for a student to take an active role in the learning process, such as performing data analysis or discussing opposing arguments (Osborne, 2010; Marienau & Fiddler, 2002; Brooks & Brooks, 1999). As a result, few students are able to develop a vigorous understanding of the real scientific world (Miller et al., 2010; Parker et al., 2008), while others may miss out on the concept of how actual science
works. In turn, this results in limited levels of understanding of the actual science content (Schwartz et al., 2004; Bell & Linn, 2002).

1.4 The Challenge

According to Gabel (1994), the dominant trend with regard to the teaching of science in the 21st century is that of being sure to “cover all the material” (p. 78) instead of building up the students’ scientific skills. The acquisition of knowledge under this method is described by the Mathematics and Science Study (TIMSS) as being “a mile wide and an inch deep” (Schmidt et al., 2004, p. 3). As an example, Meyer and Jones (1993) reported that four months after a psychology class had ended, the students in their study knew only 8% more about topics covered in the course than students who had never attended the course.

Increased understanding about the way humans learn, has led to an increased call to incorporate practical learning and critical skills into the curriculum, and to transform learning from a passive to an active process (Handelsman et al., 2004). Many studies support students’ participation in the learning process, and note positive effects on students’ learning outcomes (Ma & Nickerson, 2006; Chickering & Gamson, 1987). Although the methods and techniques used in research science have changed over the past three decades, similar modifications in teaching approaches are far less noticeable (American Association for the Advancement of Science, 2011, Glenn, 2000; National Science Foundation, 1996). Two reasons may account for this disconnect. First, some faculty members lack awareness of the strong demand for student-centered learning, which has resulted in lack of development of learning theory (Fox, 2003). Second, some faculty members prefer to spend their time and work in the research field rather than discovering effective teaching methods (Savkar & Lokere 2010; Wieman, et al., 2010)
Students’ interest in course material and their positive learning outcomes are strongly correlated (Handelsman et al., 2004). A successful way to inspire their creativity and level of motivation is to challenge students by offering them stimulating curriculum (Kitchen et al, 2007; Lee et al., 2004).

1.5 The Result of the Problem

After experiencing traditional methods of teaching science, which emphasize a type of competition for grades rather than learning, students often suffer from information overload and many lose their passion for science, and some change their major to non-science fields (Wolfson et al., 2015; Seymour & Hewitt, 1997; Seymour, 1995). Students have also reported that poor educational methods were the main factor responsible for their decision to leave science, technology, engineering, and math (STEM) fields (Hurtado et al., 2010; Seymour & Hewitt, 1997).

Even now, in 2015, despite the large numbers of studies showing the benefits of active learning, the majority of science courses still utilize a typical teaching approach where the instructor is centrally located, lecturing to students on facts that show no relation to their real lives and asking them to memorize them (Vance-Chalcraft et al., 2007). This approach is an advantage to the instructor because it enables the teacher to cover a good deal of course material in a short period of time. Yet, the students who gain knowledge via this method are not typically encouraged to proceed in the field of science (Marienau & Fiddler, 2002).

1.6 A Call to Action

Regrettably, there is a gap between students’ lives inside and outside their school that is
becoming increasingly clear (Weber, 2014). School should be a place to acquire both knowledge and skills. Although knowledge is necessary for success on school exams, skills are essential for the future success of students in their job, regardless of field, as well as in their personal life (Webster, 2015). A technique known as problem based learning, which involves critical thinking about a problem with team members and providing reliable solutions, is one of the decisive skills that the American Association for the Advancement of Science (AAAS, 1994) says students must acquire in order to succeed in the real, post-school world (Chin & Chia, 2004; Gallagher, 1997; Brooks & Brooks, 1999).
CHAPTER 2
LITERATURE REVIEW

2.1 History of Problem-Based Learning

The call for learning methods that use and develop problem-solving skills was raised early in the 20th century; both Kilpatrick (1918) and Dewey (1938) commented on this, criticizing the traditional educational system. Both noted that the established educational system ignores the learning of skills through practical experience, and recommended emphasizing learning through a problem-solving format instead. By the 1960s, the application of problem-based learning was well established at Harvard University (Christensen et al., 1991), and it has been implemented by a number of colleges and high schools since then. Later, the decision to improve the problem-solving skills of students became one of the main goals in the field of science education (Palacio-Canyetano, 1997; Lavoie, 1993). Today, this style of learning is referred to as problem-based learning (PBL), and a great deal of research has helped to define this teaching and learning technique (Tan, 2004; Torp & Sage, 2002; Barrows, 2000). These definitions describe the role of students and teachers, as well as the diverse types of problems that can be used in PBL systems. Barrows (1998) underscored the role of the teacher as simply guiding the process without providing knowledge. Barrows (2000) also defined PBL as a way to teach students how they can think and act. Similarly, Torp and Sage (2002), describe PBL as an investigation of a significant problem where students work as a team, with the assistance of the facilitator, to collect the information that allows them to solve the problem or a case. Other sources have depicted PBL as a model where students occupy the center of the learning process, transforming from passive to active learners by being responsible for collection of the required knowledge and by developing the demanding skills needed to solve problems that arise during
the process (Tan, 2004; Major et al., 2000; Mechling, 1995; Mayo et al., 1993). Unlike traditional methods that supply the problems after providing the theoretical knowledge, PBL first posits the problem in order to better stimulate the student's interest and ability to understand as well as aids in the development of skills for lifelong learning (White, 2002, see Figure 1).

Problem based learning

![Diagram comparing PBL to traditional learning](image)

*Figure 1. Comparison of PBL to traditional learning (Andres et al., 2015, p. 3).*

2.2 Forms of PBL

PBL can take various forms depending on the learning objective of the instructor, and they range from less infusion of PBL to more.

In 2011, Hung, (p. 533-536) reviewed the different models of PBL based on Barrows work (1986, pp. 483-484); Barrows model is provided in Figure 2.
Figure 2. Barrow's PBL taxonomy (Hung 2011, p. 534).

- **Lecture-based with problem solving activities:** in this model the whole curricula is lecture-based format but combines a few problems just as an example or test. The knowledge is presented first, followed by the problem (Hung, 2011; Barrows, 1986).

- **Case-based learning** also depends on lecture to deliver the information. A course of this type begins with the presentation of an historical case to introduce the topic for that class. Cases are analyzed by students before the instructor offers any further information or input (Hung, 2011; Barrows, 1986).

- **Project-based learning** is commonly used for education in law and business. As a norm, the whole curriculum is designed to fit into one case. Students must do their own research and share their work in discussion with the instructors (Hung, 2011; Barrows, 1986).
• *Modified case-based method or Anchored instruction* is where students are divided into small groups where they plan the approach that solves the respective problem, depending on pre-explained knowledge by the instructor (Hung, 2011; Barrows, 1986).

• *Hybrid PBL* is combined a traditional lecture with study cases (PBL). The instructor presents the problem with no previous explanation. This challenges the students’ prior knowledge and forces them to seek out new knowledge to support their hypotheses and provide needed evidence (Hung, 2011; Barrows, 1986).

• *Pure PBL*: There is no lecture in this model, just “ill-structured” problems with no previous clarification (Hung, 2011; Barrows, 1986).

2.3 Hybrid PBL

This study focuses on hybrid PBL (H-PBL). H-PBL does not require redefinition of the whole curriculum; instead, PBL can be established as a teaching method for a part of the curriculum, making it suitable for schools that reject completely converting their traditional curriculum into pure PBL. H-PBL was first studied by Hans in 2001, then by Pepper in 2008. However, both of the previous studies depended on qualitative data, but neither the quantitative data of this method nor use of a control group were considered. Yet there are three studies that highlight the efficiency of this approach:

• Callis et al. (2010) compared the performance of 40 dental practitioners in a hybrid PBL class to 31 dental practitioners taught in the same course but all in traditional lecture format. The results of the essay question assessments were compared between the two groups. The findings demonstrated that the hybrid PBL significantly enhanced student science comprehension (p=.01), hypothesis generation (p=.016) and communication (p=.006).
• In a longer term study by Carrió et al. (2016) on biology students from Barcelona university, over four year biology program, students experienced 20% of their curriculums in PBL forms while the rest was delivered in traditional lecture form. Students from H-PBL recorded statistically significant higher long-term knowledge acquisition than students who experienced mainly lecture-based format (p=0.041).

• In a medical military school in China, Lian and He (2013) also conducted a hybrid PBL study where PBL format represented 40% (nine study cases) of lecture-based curriculum. The data were collected from 101 participants in hybrid PBL and 104 participants in a lecture based class. H-PBL students exceeded lecture-based students in problem solving skills and knowledge acquirement and also registered significantly higher scores in their final biochemistry exam.

2.4 PBL Aims

Several studies have summarized the broad purposes that PBL may serve.

2.4.1 Building More Flexible or Malleable Knowledge

Flexible knowledge is the ability to apply the same concepts to different situations (Hmelo-Silver 2004; Cantillon et al. 2003). PBL students have a greater ability than traditional curriculum students to apply scientific explanations to a new problem that was not part of their curriculum (Derry et al., 2002; Norman et al., 1998; Patel et al. 1993).

A more flexible knowledge base provides a bridge between several cognitive domains (Chi et al., 1981). Thus, such learners can modify their knowledge to be most appropriate to each specific situation (Kolodner, 1993; Bransford et al., 1990). The ability to put knowledge into
different templates is a demanding skill learned under PBL systems. And, according to Hmelo et al. (2000) and Needham and Begg (1991), PBL can serve as an advocate for such skills in either classroom or lab sessions.

2.4.2 Enhancing Problem-Solving and Lifelong Skills

Problem-solving skills can involve multiple sub-skills, such as higher order thinking (metacognitive), analogical strategies and logical strategies (Kolodner et al., 1996; Kolodner, 1993). These skills help students deal with real-life problems, where they need to make careful decisions and act wisely (Uden & Beaumont, 2006, p. 50). Traditional curricula rarely deal with such important skills (Koschmann et al., 1994). Lieux (1996) reported on some interesting studies in a nutrition course where students observed how appreciably PBL improved their communication and problem solving skills. Students began by recalling prior knowledge and experience relevant to the problem at hand. Since not all information can be automatically recalled from memory, more thought, reflection, and review was required to activate other information, and students needed to investigate the problem in a deeper manner. In addition, new knowledge must be acquired in order to expand and correct the gaps in students’ prior foundational knowledge. Activating reflection knowledge assists students in deciding what resources are appropriate to use, where they can find them, and how such resources can be utilized. These processes are referred to as “metacognitive skills” (Borrows, 1988). In addition, Shepherd (1998) reported a remarkable increase in metacognitive skills among fourth and fifth grade students after participating in a PBL course. Similar results have been observed in the medical field by Hmelo (1998). In the field of mathematics, after analyzing data using Keller’s instrument and meta-cognitive awareness inventory, the application of a PBL system was found
to positively affect students’ cognitive skills and awareness (Tarmizi & Bayat, 2010). The effectiveness of PBL methods in improving the cognitive skills of students has also been shown in mechanical engineering (Alias & Saleh, 2007).

2.4.3 Transitioning Students into More Self-Directed Learners

To be a self-directed learner, students begin by defining their goals and what knowledge they lack in that regard. They then choose the strategies required to achieve these goals, followed by performance assessments to evaluate whether they have met the goals (Dolmans et al. 2005; Zimmerman, 2002; Hmelo & Lin, 2000). Several studies have demonstrated the effectiveness of PBL in improving self-directed learning ability (Distlehhorst et al., 2005; Blumberg & Michael, 1992).

2.4.4 Promoting Teamwork to Solve a Problem

Unlike classical learning, students utilizing PBL work as a team, which may have a positive impact on their future careers and social lives (Uden & Beaumont, 2006). When group members come from diverse backgrounds, these students also tend to become more open-minded, accepting views from a variety of people (Uden & Beaumont, 2006; Banta et al., 2000). The variety of life experience and knowledge that each individual member brings to the group enhances the sharing process toward solving a problem in a way that one person’s solitary experiences cannot (Salomon, 1993). Further, during the PBL process, students are able to share their different points of view and find a common plan for all to follow (Barron, 2000). Each team member is encouraged to be engaged and freely share ideas and knowledge with
other members (Wenger, 1998). Studies like the one done by Johnson et al. (1985) have confirmed the value of cooperation with respect to the learning process.

2.4.5 Increasing Student Motivation to Learn.

When the course material engages and motivates students, learning outcomes increase significantly (Svinicki, 2004, 2011). This association has also been reported by Rowe et al. (2011) where crystal land, a 3D game for eighth grade students, was utilized as a part of a microbiology course. Their study results concluded two improvements, first, students’ performance to solve the problem that the game involved and second, their learning outcomes. The challenges themselves, which are inherent in PBL, motivate students to learn (Langelotz et al., 2005; Ferrari & Mahalingham, 1998). For example, after introducing a PBL system into the surgical curriculum in a medical school in Germany, students’ motivation increased relative to traditional students motivation (Langelotz et al., 2005). In addition, a noticeable improvement in motivation was seen among students who were taught physics via the PBL system (Garcia, 2011). A similar result was reported when PBL was applied to chemical engineering students (Mohd-Yusof et al., 2011).

2.4.6 Inspiring Critical Thinking

Critical thinking is described as the ability to provide a reliable mental evaluation of a situation that is derived from robust evidences (Hamby, 2007). Since students are future employees, they need to use careful judgment with regard to the problems they face, options they have, and actions they take. Teaching critical thinking can be achieved by identifying a problem, then finding and evaluating multiple solutions (Chubinski, 1996). Due to its unique
characteristics, PBL can offer a positive environment in which to gain critical thinking skills (Uden & Beaumont, 2006).

2.5 The PBL Triangle

The essential elements of PBL can be illustrated using a triangle, where the student, teacher, and problem each make up one of its three angles. Each of these three elements has a significant role to play toward the successful application of PBL.

2.5.1 The Teacher's Role

Working in groups is a basic theme of PBL. And, even though students are at the center of this learning process (Aspy et al., 1993), they still need a guide to function effectively together (Barrows, 2000). In PBL, teachers are facilitators, and work on focusing and promoting group discussion, providing illustrative examples, narrowing down the discussion to remain on target, and evaluating student performance (Posner & Rudnitsky, 2001). PBL teachers are not providing direct knowledge; the teacher in PBL motivates students to deal with the problem by asking metacognitive or other types of questions to foster students’ attention (Hmelo-Silver & Barrows, 2003), especially when they get off track (Woods, 1997b). This requires teachers to be experts at diverse learning and thought strategies, rather than just master of the content. Facilitators also serve to ensure that each group member is involved (Hmelo-Silver, 2002).

In medical school, Hmelo-Silver (2002) proposed a method to inspire intellectual exploration when lack of knowledge was an issue among his students, by asking them to explain evidence that supports their views. In another case study, he asked them about the link between their hypothesis and the respective patients' syndromes. These case studies demonstrate the need
for a flexible facilitator who can use appropriate strategies to meet the goal of educating the students through the use of PBL. One model to manage the facilitator’s role, suggested and applied by Hmelo-Silver (2002), is called “a wandering facilitation model” (p. 246). In this model, the teacher goes around the classroom and follows students’ progress by looking at the tracking board that each group creates to work on the problem.

The teacher as facilitator is also responsible for providing a positive environment that assists self-learning, where students can work to gain the required knowledge (Aspy et al., 1993). In addition, this requires the teacher as facilitator to provide a safe environment where students are confident to work without any fear of feeling inadequate (Virjo et al, 1999).

Moreover, in order for PBL to be successful, proper preparation of the conversion of teacher to facilitator that is involved in this teaching style is critical (Farmer, 2004). Studies have evaluated the use of special workshops to prepare PBL teachers. For example, an education course with 39 class hours was introduced for junior teachers that focused on integrating the metacognitive skills required to solve a problem by starting with “what if” questions to figure out strong and weak points in their educational backgrounds, what areas of knowledge they needed to work on, and how they might acquire that knowledge (Etherington, 2011).

2.5.2 The Student’s Role

The second angle of the PBL triangle is the student. Taking into account how they think and learn is an essential part of successful PBL (Beadling & Vossler, 2001). Several studies have emphasized the importance of preparing students to shift from participation in traditional classes to PBL classes, as well as to inform them of the potential benefits of the PBL approach (Uden & Beaumont, 2006).
In addition, the variation in student levels within a diverse group of learners requires designing a problem suitable for all such levels to bring students together. Taking into account the student differences also positively affects the individual learning experience (Suinn, 1999). Since students’ preferences in learning style often vary, considering this will support their participation in a successful PBL (Coffield et al, 2004).

And finally, addressing the problem is a problem. Several studies have been performed to better understand how students address problems. One such study presented a “think aloud” method where, as students go through the problem, they express aloud their process of asking questions and their trials to reach their resolution, which serves as a reflection of their thoughts (Chi, 2006). Card classification has been also utilized to increase understanding of how students identify problems. In this technique, students are asked to classify cards into groups depending on how they relate to each other (Chi, 2006). This research also distinguishes novice and expert handling of a problem and includes the use of either a deep or surface approach to viewing the problem, which shows how one organizes knowledge. The way the knowledge is being organized enables an expert to utilize their background and do brief research to solve the case, unlike novice learners who organize their knowledge differently and need more time to do their research (Reif, 2008).

2.5.3 The PBL “Problem”

The third angle of the PBL triangle is the problem itself. In order for the problem to meet its objective in PBL, it should have some or all of the following criteria:

- It should be authentic. This is identified in the literature in several ways, such as open problem (Bolton & Ross, 1997) or having social or personal linkage (Wenglinsky & Silverstein,
2007), or the possibility of more than one solution (Steen, 2005; Brownell et al., 2011), or being a real-world problem (Gormally et al., 2012) the latter of which is called an “ill-structured” (Hoskinson et al., 2013).

- It should be complex. The second aspect of PBL’s problem comes from the agreement to utilize complex problems that stimulate advanced skills (Jonassen, 2011). The main features of complex problems are diverse variables and elements (Fischer et al., 2012; Goldenfeld, 1999). Complex problems also require the use of specific skills to deal with them (Smith and Good, 1984) and that cannot be easily solved by simply recalling knowledge (Fischer et al., 2012).

- It should be at the right level for the students. Not too high, which may demoralize the learner, and not too low, as it must meet the PBL target (Suinn, 1999).

2.6 PBL in the Science Laboratory

Different science majors (medical school, biology, physics, and chemistry) are fertile fields in which to apply PBL, both in classes and in the laboratories (Gök, 2010). Medical schools started applying PBL techniques ahead of some other field, this trend then has grown, and at one point was used in 80% of medical institutions (Vernon & Blake, 1993). In addition, a wide variety of academic institution have incorporated PBL in their curricula, ranging from middle and high school (Barrows & Myers, 1993; Hmelo-Silver, 2004) to college and university levels, such as science (Ünal & Özdemir, 2013), psychology (Abdul Razzak, 2012), business (Belt et al., 2002) architecture, computer science, and social work (Wood, 2009; Boud & Fletti, 1991).
As the trend toward applying PBL has grown and the positive results of PBL on improving student skills have been documented, more organizations in the United States have been established to instill standards and offer recommendations in science education. For instance, the board of Engineering and Technology has reported that education should involve more problem-solving skills and enhanced communication between students (Volkwein et al., 2004). The American Chemical Society has also called for more creative educational methods since 1968. The Union of the American Physical Society, the American Association of Physics Teachers, and the American Institute of Physics have designed various programs in search of the most successful educational approach in physics (Ferrini-Mundy & Gucler, 2009).

The movement toward incorporating PBL in physics courses began over thirty years ago (Hsu et al., 2004; Heller & Reif, 1984). The calls for applying PBL have recently become louder when concern about students’ deep understanding came to the forefront (Kelly & Finlayson, 2010; Hestenes & Swackhamer, 1992). Further studies with respect to PBL have been reported in physics including multiple aspects of problem solving and the criteria for effective problem solving (Reif, 2008). In addition, studies have analyzed the strategies that students follow in this process (Larkin et al., 1980) to discover the role of conceptual knowledge in PBL. Moreover, various studies on finding tools and instruments to support deeper learning using PBL have become available (Pawl et al., 2009; Mestre et al., 1993). Current literature is replete with applications of PBL in physics curricula. For instance, in 2013, Ünal and Özdemir designed a problem solving physics lab. In this lab, students were provided with six laboratory sheets, each of which had a real life problem followed by nine questions designed to help students recognize the physics concepts behind each problem. A hypothesis to deal with the problem was then designed and tested using practical work and observation. Finally, experimental variables were
defined and students evaluated their solutions and gave recommendations for dealing with the current problem.

Chemistry is another field of science that researchers such as Neeland (1991) and Hollingworth & McLoughlin (2005) say has suffered from traditional lab teaching methods that ignore critical skill development. According to Wilson (1987), although chemistry depends mainly on experimental work, the actual teaching of how to design a logical experiment is all too rare. To ameliorate concerns such as this, Kelly and Finlayson (2007) modified the traditional chemistry lab for first year undergraduate students, implementing a PBL lab format with a pre-lab session to introduce some theoretical background for the coming experiments. Instead of changing the entire course curriculum, modification of the existing experimental style was done to involve more cooperative work in productive surroundings, followed by using evaluation tools to assess the results of the new PBL-lab format. Similarly, the University of New Mexico piloted an online version of PBL in its biochemistry department, where small groups of learners participated in solving a scientific problem (Anderson et al., 2008). In another chemistry course example, Parker Siburt et al. (2011) introduced a problem manipulation method (PM²) where solving the given problem was not the only task; but the students were also provided with a new problem linked to the given problem to solve it as well.

As with physics and chemistry, learning and practicing problem-solving skills is equally as important for biology students (AAAS, 2011; Dirks, 2011). The majority of new trends in teaching biology are aimed to active learning (Beadling & Vossler, 2001), and seek to increase students’ motivation by using games (Bowling et al., 2013; Barclay et al., 2011), conceptual maps (Kaiser, 2010), and social media, and broadcasting (Racaniello, 2010). However, according to both the National Research Council (NRC) (2003) and the American Association for the
Advancement of Science (2010) studies on the incorporation of PBL in biology curricula are insufficient in number. Therefore, the NRC (2003) began emphasizing its use in the biology curriculum and calls for the teaching of biology to be done in the same manner as the information in the course is originally produced (AAMC & HHMI, 2009). Specifically, the American Society for Microbiology has generated criteria for teaching microbiology, highlighting the use of PBL (ASM, 2002, 2012); and the AAAS Vision and Change report makes similar recommendations (AAAS, 2011).

Maybe the limited application of PBL within the field of microbiology is due to the fact that problems in biology differ in their structure and content from those in physics or chemistry (Hoskinson et al., 2013). The main difference may be the incomplete nature of problems in biology, which still call for more investigation (Nehm, 2010). However, all of these subjects meet in terms of how hypotheses are designed, defined, and approved (Hoskinson et al., 2013). Thus, according to Hoskinson et al., (2013) it is possible for the field of microbiology to implement some of the more successful approaches used in the teaching of other science subjects (Hoskinson et al., 2013).

Although some microbiology teachers have experienced using the PBL system in class sessions (Allen and Tanner, 2003), the application of PBL in microbiology laboratories, aside from medical microbiology laboratories (Pepper, 2009), has not been sufficiently tested. Over the years, there have been a few PBL models have been successfully applied in biology classrooms such as the PBL scenario model, the patients’ model and the group-based learning model. A problem-based scenario model might begin with a story in order to get students more involved. Then students offer a hypothesis and test it in a logical manner. Ultimately, they assess the evidence supporting the hypotheses (Norman & Schmidt, 2000). Currently, in the medical
microbiology field, it is common to use a series of case studies involving patients with defined symptoms and laboratory results. In this type of PBL, the students’ task is to diagnose the patient’s disease depending on robust evidences (Ciraj et al., 2010). The use of group-based learning has been used previously in microbiology, under the term team-based learning (Fink, 2002). In this cooperative model, students work in groups to accomplish challenging tasks. Studies using this model of learning found several positive effects, including improvement of students’ skills and grades (Trempy et al., 2009; Hoffman, 2001), as well as increased interest in microbiology (Buxeda & Moore, 2000).

However, there are some obstacles that may face microbiologists when applying PBL including the enormous amount of knowledge that each microbiology class demands (Merkel, 2012). This might be solved by responding to the recommendation of reducing the amount of information in the curriculum before applying PBL (Gregory, 2011; Cheesman et al., 2007). Another concern, according to Carrió et al., (2011), has been whether incorporation of PBL is sufficient to teach both the theoretical content and critical skills needed. In an investigation of this issue by Carrió et al. (2011), in hybrid PBL (H-PBL) class where 20% of a biology course curriculum was PBL-oriented, with the remaining 80% based on lecture based learning, no significant differences with respect to learning content were found between H-PBL and lecture based students. In addition, no distinctions of any significant degree were reported when Vernon and Blake (1993) compared knowledge of PBL students and traditional curriculum students.

2.7 PBL in Practice

In the initial class, the instructor explains the PBL system to the learners (Akınoğlu et al., 2006), and provides some examples.
1. Students are divided into small hetero-groups. Some studies also assign “a chair person” for each group to enhance and record the workflow (O’Toole, 2012).

2. The problem is then presented (Barrows, 2000) in one of the following ways:

3. As written text (Davis & Harden, 1999), also known as a “thin-narrative” paper case (Chan et al., 2012).

4. As a “media rich” or “thick-narrative” where the problem is delivered in the form of a video (Chan et al., 2012; Bizzocchi & Schell, 2009).

5. In the medical field, a real patient can tell his or her problem directly to the students (Diemers et al., 2007), or they may view recorded clips of real patients’ complaints.

6. There is an opportunity for students to ask questions to clarify the problem, or they may perform small experiments to discover the answers (Torp & Sage, 2002; McManus & Gettinger, 1996).

7. Group members also cooperate throughout a discussion in order to share different perspectives to engender greater clarification of the presented problem (Bahar, 2003).

8. In some modified PBL work, model discussion occurs, not only during the PBL session, but also before (Kelly & Finlayson, 2007), which is referred in literature as “pre-lab” sessions. Johnstone (1997) pointed out the purposes of this pre-session, which include designing the hypotheses, and works’ plan derived from peer discussion. The pre-lab or pre-lecture are considered as being effective tools toward the preparation of students’ mind (Johnston, 1997).

9. Students then perform their own research in order to determine what solution(s) they are able to reach and then apply what they learn and share their conclusion. In addition, A face-to-face meeting is not the only way for students to communicate and exchange their knowledge,
as they can also incorporate social network technology, such as a mobile phone, Skype, social media or any other available form of technology (Howe and Schanable, 2012).

10. At the end of the PBL session, the instructor provides the students with the evaluations and feedback for their work (Woods, 1997a) (Figure 3).

![Figure 3. The problem-based learning cycle (Hmelo-Silver, 2004, p. 237).](image)

2.8 PBL Assessment

Assessment has a great impact on students’ work (Lipnevich & Smith, 2008). By utilizing the proper evaluation tools, the assessment results can reflect how much students have learned and understood. The evaluation of students’ performance is considered to be the most challengeable part of PBL (Savin-Baden, 2004), as PBL targets two aspects: acquisition of skills and acquisition of knowledge. The assessment of both of these elements should be taken into account (Swanson et al., 1997).

In general, instructors mostly provide the assessment, but in some PBL models, students are responsible for assessment of their own work (Swanson, 1997), after they are given the
criteria by which they should evaluate it (Wood, 1995). Uden and Beaumont (2006), and Savin-Baden (2003) both strongly support this approach.

2.8.1 Curriculum knowledge Assessment

According to Norman (1997, p. 264), “Since knowledge and problem solving are closely related, then we may unapologetically ask that our students know something and we may, and should, test for knowledge.” Some researchers advocate using multiple-choice questions to test students’ knowledge (Uden & Beaumont, 2006; Wood, 1995). A number of traditional methods of evaluation have been used in PBL classes in order to evaluate knowledge. In some studies, knowledge evaluation occurs via written report, which contains the work summary, concepts, and the collection of data and resources or students can present their final work through a concept map, which displays a student’s degree of understanding by presenting the work visually and showing the linkage between pieces of information that led to the problem resolution (Daley et al., 1999). It is also possible for students to present their work by oral presentation in front of peers and/or professors. This type of display of information has received a great deal of attention, as it provides more than that contained in a written report (Wimpfheimer, 2004, Allen & Tanner, 2003). Moreover, preparing a poster can also measure student creativity with respect to the presentation of their data. In research conducted by Wimpfheimer (2004), it was reported that the advantages of using posters including motivating students to be more creative in presenting their data and advocating cooperative work was also to put the main points in a limited sized format. In addition, both student and teacher indicated they enjoyed working on and dealing with the posters.
2.8.2 Evaluation of Skills

A number of instruments and tools have been developed to assess some specific skills that PBL targets, such as problem solving (Parker et al., 2012), critical thinking (Bissell & Lemons, 2006), and the basic skills of processing information (Gormally et al., 2012). Beadling and Vossler (2001) used a study that depended on two instructors: one to work as a problem guide and the second to estimate the students’ contribution skills. Another study recorded the PBL session to evaluate student cooperation skills (Davis & Harden, 1999). The Study Process Questionnaire (SPQ) measures depth of learning, and has been used by other studies (O’Toole, 2012; Mok et al., 2009). Other studies depend on peer evaluation for assessing student contributions (Uden & Beaumont, 2006). The Problem Solving Skill Perception Inventory (PSSPI) (Heppner & Petersen, 1982) is used to measures student’s confidence levels with respect to their problem solving skills. Another instrument is the Scientific Process Skills Test (SPST), which considers the students’ ability to identify the problem variables, draw hypotheses, design and illustrate visual graphs, and provide practical explanations (Molitor & George, 1976). The Individual Problem-Solving Assessment (IPSA) aims to evaluate students’ problem solving skills by digitally posting new problem scenarios that were not covered in class. With this tool, students go through problem solving material using variety of sources as they taught. They then evaluate their achievements and propose ideas to improve them (Seyhan, 2014).

To get feedback on how students understand and respond to PBL, a couple of pre/ post open-ended questionnaires and surveys have been utilized (Winning et al. 2012; Kember & Leung, 2006). In addition, since the facilitator’s performance is critical in PBL, Dolmans and Ginns, (2005) evaluated the effectiveness of the tutors in PBL approach.
2.9 Bloom’s Taxonomy

Bloom and his colleagues (1956) classified cognitive skills into six categories: remembering (knowledge), comprehension (understanding), application, analyzing, evaluation and creating (Figures 4 and 5), known as Bloom’s taxonomy. The first three levels (knowledge, comprehension and application) require low order thinking while the last three levels demand higher levels of thinking. Faculty and researchers can design different levels of questions, each of them reflecting a specific level of understanding in this taxonomy to evaluate their students. While this tool has been available since 1956, its application in higher education is still limited (Athanassiou et al., 2003). In one study, a number of professors analyzed their biology exam questions according to Bloom’s cognitive levels, and found that about 25% of the questions tested high-level thinking skills while the majority (70-75%) tested low level thinking (Figure 6) (Crowe et al., 2008; Lord & Baviskar, 2007; Bloom et al., 1956). Recently, a number of studies have modified and developed Bloom’s taxonomy as an assessment tool in biology exams (O’Neill et al., 2010; Crowe et al., 2008; Allen & Tanner, 2007) or to generate rubrics designed to evaluate students’ performance (Bissell and Lemons, 2006).

Use of Bloom’s taxonomy when designing course material provides multiple advantages, and several studies reveal that implementation of this tool enhances both education and learning. Crowe et al. in 2008, noted,

While developing the Blooming Biology Tool (BBT), we found that the very process of developing the BBT was strongly influencing our own teaching in the classroom. The BBT was guiding us to ask and write better questions, develop more appropriate learning strategies, and assist our students in the development of their metacognitive skills. This tool provided us with a means to consistently apply the principles of Bloom’s to biology concepts and skills, thus allowing us to better assess student-learning outcomes. (p. 373)

The same study found that using BBT in the classroom affects students’ study habits and ability to answer different levels of questions. Furthermore, Bloom’s taxonomy offers standards in
designing questions testing each level in this taxonomy, which makes it a practical tool for faculty to align their assessment with the activities (Allen & Tanner, 2002).

Figure 4. The original version of Bloom's classification of learning levels (Bloom et al., 1956).

Figure 5. The revised version of Bloom's classification of learning levels (Anderson & Krathwohl, 2001).
2.10 Research Theory

Despite the value of applying PBL to science, its application in the microbiology laboratory have not yet addressed sufficiently. More reliable studies testing the value of PBL in the microbiology class and laboratories are greatly needed. In order to investigate the full effect of PBL in the microbiology laboratory, the following theory was designed:

H1: Students who learn microbiology concepts via problem based learning will be able to answer three levels of higher order questions as defined by Bloom’s taxonomy, in comparison to students who do not learn Microbiology concepts via hybrid problem based learning.

Ho: Students who learn Microbiology concepts via hybrid problem based learning will not be able to answer three levels of higher order questions as defined by Bloom’s taxonomy, in comparison to students who do not learn microbiology concepts via problem based learning.
CHAPTER 3

METHODS

This study (IRB Number: 15-378, Appendix A) sought to investigate the potential effects of a hybrid problem based learning (H-PBL) model and its effect on higher-order thinking among first-year university students in an introductory microbiology lab. The experimental design compared the learning outcomes of two groups of students: the H-PBL group (20 students from Spring 2016 and 21 students from Fall 2016) and the control group (22 students from Spring 2016 and 21 students from Fall 2016). There were no noticeable differences between the control groups of Spring 2016 and Fall 2016 regarding their attendance and their laboratory final exam scores, so we combined them into one control group containing 43 students for data analysis. The same process was applied to the H-PBL groups from Fall 2016 and Spring 2016, resulting in one H-PBL group containing 41 students. Both groups were taught basic skills for the microbiology lab by the same instructor. Using the traditional teaching style for the control group, the instructor offered each student what they needed for their experiments (protocols and expected results). The H-PBL group practiced experimental design, data analysis, theory proposal, and created research questions by using six study cases that are closely linked to the area of study. The goal of this study was to determine if the H-PBL group would perform better on higher order questions, based on Blooms’ taxonomy, in an assessment designed by the researcher.

3.1 Participants

Participants were students at the University of North Texas in Denton, Texas, enrolled in two different laboratory sections of the same microbiology course taught by the same instructor.
Students are required to take general chemistry and general biology for science majors before taking the microbiology class and laboratory. As a general rule, most students take the microbiology course in the second year of their bachelor program as a core course.

The participants self-selected randomly, “which result[ed] in an equal probability of selection for all elements in the population” (Ross, 1978, p. 9). A number of variables (age, gender and major) were considered when analyzing the results to ensure the equivalence of the two sections. For example, the ages of the Students in the control group ranged between 20 and 24 while the ages in the H-PBL group ranged between 19 and 25.

Students in the H-PBL section were informed that they would be participating in extra activities in the syllabus and asked for their consent. Students who don’t agree to take apart in this study were excluded from the experiment.

3.2 Course

H-PBL cases were embedded in the traditional curricula to two H-PBL groups during two semesters of a microbiology lab (spring 2016 and fall 2016). The H-PBL cases were not implemented with the two control groups that were taking the course at the same time. For all students, the class met for 3 hours per week and the laboratory section met for 4 hours per week. The laboratory is designed to provide hands-on experiments that support the course material. In such a lab (see Appendix B for the syllabus), students learn basic skills and techniques with respect to the use of a microscope, microbial culture, microbial staining, and environmental influences on microorganisms. They then study these microorganisms from a molecular and genetic perspective. Lastly, students use what they have learned from the entire course to identify unknown species after doing a series of biochemical tests. In the control group, the instructor
provided the students with all the information and experimental designs, and the students didn’t do any research to figure out how this protocol can be derived or applied to another situation. The H-PBL group also had these protocols provided on the day of doing the experiment. However, the H-PBL group had a case study posted online for them one week before the actual lab, and they were required to do their research to design the experiment and derive the experimental theory, questions, and other applications for using these protocols. Both the H-PBL and the control group had the same laboratory syllabus and manual, which included the topics that the study cases cover.

3.3 H-PBL Instructor

The instructor for both sections was Claudia Gonzalez-Villarreal. She is a graduate student in the Department of Biological Sciences at the University of North Texas (UNT), Denton, Texas. She obtained her Multidisciplinary Bachelor’s degree with a major in chemistry, pharmacology and biology and a minor in food science from Autonomous University of Coahuila, Mexico in 2010. Before attending UNT, Claudia worked as a laboratory assistant in the Polymer Synthesis Department of the Investigation Center in Applied Chemistry in Saltillo, Coahuila Mexico (CIQA). Since coming to UNT in 2013, she has taught microbiology labs and has received good evaluations (top 50% of her peers) from her students during this time.

3.4 Problem Design

For the H-PBL group, six lessons from the course were selected to be taught using a problem or a case study related to each lesson. A period of at least one week separated the lessons, which allows the application of PBL. Hence, the course was in H-PBL form, not pure
PBL. PBL cases represented 30% of the curricula in the form of six study cases while the rest of the course was delivered in traditional format. These cases were selected or designed according to the criteria indicated in section 2.5.3; so that the problems associated with each lesson meet the PBL objectives (see appendix C for cases).

3.5 Materials

In the six microbiology cases given to the H-PBL group (see Appendix C), the researcher used diverse resources such as websites, news, books, and articles to design problems that fit with the previous criteria (see section 2.5.3). One problem was modified from the microbe world website (http://www.documbase.com/Mega-Multiples-of-Microbe); this case deals with a mega-multiple of microbes. Two cases about the effect of UV light and the temperature on bacterial growth were taken from the book, *Laboratory Applications in Microbiology* by Chess (2014). The fourth problem, which was about antibiotic resistance, was based on bacteriology science fair projects written by Leonard from Mount Mary College (2012). The fifth problem, which was about the Ebola epidemic, was drawn from the National Center for Case Study Teaching in Science collection, written by Allison Black and Annie Prud’homme-Généreux from Quest University, Canada (2012). The last case, which was about a gram stain, was written by the investigator based on personal experience (2015).

The students’ tasks with respect to these problems were to design an experiment, conduct data analysis, generate a theory, propose a data argument, and design research questions. All of these tasks required the use of higher order thinking skills as defined by Bloom (1956). These cases were not given to the control group and the control group did not participate in doing them.
3.6 PBL Session (Procedure)

Sessions for each of the six cases followed the procedure outlined above in section 2.7. Specifically, students were divided into groups of 4-5 who vary in their microbiology background. The cases were posted online to the H-PBL group one week before they had to present a solution, and then the problem-solving process began (Figure 7). Students had the opportunity to ask questions to help clarify the problem, perform their own research to determine what solution(s) they were able to reach, and then applied what they learned to the case. During the week, group members also cooperated through discussions to share different perspectives and engender greater clarification. Students were able to incorporate technology by using different social network platforms for these discussions. The following week, students presented their solution(s) at the beginning of the lab session, and the lab material for the day related to the problem that they had just attempted to solve. The instructor provided evaluations and feedback at the end of each session.

![Figure 7. Problem solving steps (Tarmizi & Bayat, 2012, p. 3147).](image)

3.7 Study Cases Evaluation

For control group attendance and participation represented 10% of their grade. While the H-PBL, 5% out of 10% of the participation grade was based on the study cases.
3.7.1 Anecdotal Data

In this study, anecdotal data was collected to supplement the quantitative data and allowed the researcher to assess students’ perceptions, views and feelings about the H-PBL experience.

To obtain anecdotal data, two questions were added to the departmental lab instructor evaluation asked students in the H-PBL section to leave their feedback about using study cases over the four-month period in a traditionally structured undergraduate microbiology laboratory.

Anecdotal data questions:

1. How would you evaluate your experience with H-PBL cases?
2. Are you satisfied with how H-PBL was assessed by using short-question format?

3.7.2 Quantitative Data

Quantitative data, or, the numerical values of students’ learning outcomes, was obtained by using pre/post assessment scores.

3.8 Assessment

A brief pre-course assessment consisting of 24 questions was given to both groups (H-PBL and control) to determine each student’s academic level. The same assessment was given as a post-assessment at the end of the course (Appendix D). The pre/post assessment contained the same questions in order to compare student performance at the beginning and at the end of the semester to determine if the H-PBL group and the control group would have different learning outcomes.
The assessment questions were generated by the researcher based on the revised Bloom’s taxonomy covering the six different learning levels ranging from low-order cognitive skills to advanced levels (Figure. 5). The assessment included 24 questions; four questions on average fell into each of Bloom’s levels. Questions that only required students to recall information was a test of their knowledge and represent the lowest level within Bloom’s Taxonomy. The second level asked for comprehension (understanding), which would be measured by questions that ask for a description of an entire process. Asking about providing examples or applying the information to a new situation tested the application level. These first three levels, knowledge, comprehension and application, were categorized as lower level skills. Questions with respect to analysis and interpretation of raw data were used to determine if students had reached Bloom’s forth level known as analyzing, while those questions about providing a solid argument that utilized a piece of evidence or evaluating and predicting data, were classified as being at the evaluation level. Finally, the creative level of learning was tested by asking for development of some experiment models, or the invention of something new. These top three levels (analyzing, evaluation, creating) are categorized as higher-level skills within Bloom’s taxonomy. Dr. Nathaniel C. Mills, a faculty member from Texas Woman’s University (TWU), reviewed the assessment’s questions in 2016 to ensure that they fell in the right level of Bloom’s taxonomy.

3.9 Grading Criteria

To help reduce bias, the assessment was graded anonymously. Before the grading process began, a specific ID number was written on each pre/post assessment and the upper part of each paper was folded down to hide information that identified the students and which group they were in. The papers from the control and H-PBL groups were mixed up. Students received one
point for a right answer, zero points for a wrong answer and 0.5 point for a partly correct answer (see appendix E). After the first grader (the researcher) was done grading, the second grader went through the same papers to norm students’ scores. If the first two graders couldn’t agree on the score for a particular question, a third grader was brought in to decide the score. The final assessment scores were reported. Scores obtained from these assessments compared within and between groups using independent and paired t-test.

3.10 Statistical Analysis

Pilot data was collected initially to evaluate the assessment design, the time required for completing the assessment and the study cases. Students’ responses to the study cases were also considered to insure that those cases were in the right level. The internal validity of the assessment was tested by cronbach's alpha, which is commonly used for multicomponent assessment (Carmines & Zeller, 1979, p. 44, Zahid et al, 2016). Then each item in the assessment was analyzed using spearman correlation to identify and exclude problematic items that did not meet the minimum control criteria. For example, a problematic item might indicate that the item was poorly written, leaving students confused about the question, or may misrepresent the level of thinking that the item was aimed to test. Moreover, if an item always received the same responses from students, whether they were all right or all wrong, then the item needed to be removed since it would not be assessing students at the right level. The spearman correlation test calculates the correlation between a student’s score for one specific item and the total scores of all the remaining items in that domain that a student responds to.

To reduce any bias between the two groups (H-PBL and control group) and to increase precision, students were randomly assigned to each group, and the same instructor taught both
sections. Further data about the students in each group (gender, age, major) was also collected; this data was used for linear regression to control for the influence of these variables between the two groups on the treatment effect. Linear regression is designed to explain the correlation of different confounding factors (gender, major, age, PBL activities) to the experiment results to find out which factor had the most effect and which one had the least effect on the post assessment score. The mean score of the pre and post assessment score was compared between and within study groups using a paired and an independent t-test. Finally, a one-way analysis of variance (ANOVA) was conducted to control for pretest score on the experiment and investigate if there was any statistically significant difference between the two groups regarding their performance on each level of the instrument. SPSS version 24 for MAC was used to analyze the finding of this study. The significant level set at p< .05.

3.11 Expected Results

The investigator did not expect to see statistically significant differences between the control and H-PBL groups with respect to lower order thinking skills represented by answers to questions that were intended to test the knowledge and comprehension levels. On the other hand, the investigator did expect to find statistically significant differences with regard to higher order skills, which were tested by the analysis, synthesis and evaluation questions.
CHAPTER 4

RESULTS

This study evaluated the use of hybrid, problem based learning (H-PBL) on students’ performance with high order thinking questions as measured by a pre/post assessment based on Bloom’s taxonomy. Eighty-four students enrolled into two long semesters (Spring 2016 and Fall 2016). Four of these students did not complete either the pretest or the posttest, so their data didn’t qualify for analysis. The mean age for both groups was 20.2 years. The male-female composition of this study was a ratio of 16:64.

The average of the two group’s attendance was 91.3 (control) and 91 (H-PBL). Their final laboratory exam grade was 82.1 (control) and 81.2 (H-PBL). The similarity between these two groups, allowed for final comparison (Figure 8).

![Comparing variables between groups]

*Figure 8. Comparison of the two participant groups' variables.*

4.1 Research Design

The design of this study was pretest-posttest design, which is widely used in education research, to assess the effect of a new teaching approach upon groups of students (Figure 9). This
method is a preferred method in education research as it compares the two participant groups and measures the degree of change that may occur due to treatments or interventions (Dugard & Todman, 1995). The need to include pretest step arose to eliminate the biases or the factors arising due to the nature of allocation of participants in research study.

![Diagram of pretest and posttest research design](image)

*Figure 9. Pretest and posttest research design WGb=within PBL group scores gain, BGc= between two group pretest, BGd= between two group posttest.*

4.2 Pilot Data Finding

The assessment used in this study was pilot-tested on 16 undergraduate students in a microbiology laboratory in fall 2015. Based on the result, the wordings of some questions were modified to make them more robust. The approximate time needed to complete the assessment around 30 minutes.

4.3 Internal Validity

The reliability of the assessment items was tested using Chronbach’s alpha (Cronbach, 1951) since it is widely used in multi component instruments (Zahid et al, 2016; Carmines & Zeller, 1979, p. 44). For the current study, Chronbach’s alpha was retrieved from 24 questions.
and 80 subjects: 40 in the control group and 40 in the H-PBL group. The results are presented in Table 1. The expected value of the reliability will normally range between 0 and 1, the closer the value to one the greater the reliability of the item in the assessment. Nunnally (1978) reported that the acceptable value of internal consistency is 0.7. As seen in Table 1 the coefficients range from .70 to .81, which exceeds the reliability acceptable value described by (Bohrnstedt et al., 1982, p. 361) to proceed with data analysis.

Table 1

<table>
<thead>
<tr>
<th>Study group</th>
<th>pretest</th>
<th>posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-PBL group ((N = 40))</td>
<td>.795</td>
<td>.81</td>
</tr>
<tr>
<td>Control group ((N = 40))</td>
<td>.701</td>
<td>.78</td>
</tr>
</tbody>
</table>

4.4 Inter-Item Correlations

The pre/post assessment consisted of six levels or domains based on revised Bloom’s taxonomy (Figure 5). Each level was tested by four questions. The association of each question’s domain was tested to validate that they measure the same level.

Spearman correlation takes into account weather or not the groups of items are correlated to each other and measure the same fact. Spearman correlation was used in an earlier study by Tiemeier et al, (2011) to analyze correlation between items based on revised Bloom’s taxonomy. For the purpose of this study, the item response theory was taken into consideration while running the Spearman correlation test by correlating the performance (response) of a test taker on one specific item to the overall performance of the domain of that item. As a result, Spearman
was run on 24 items for 80 participants, each item score correlated to the total item score for that domain, which means 24 correlation values were obtained. The results are represented in Table 2. The result of the Spearman correlation can be interpreted, according to Ferketich (1991, p.176) who claimed that “The higher the corrected correlation between the item and the total, generally the better the item”. The following codes were used to represent the learning level: C1: knowledge; C2: Comprehension; C3: Application; C4: analysis; C5: evaluation; C6: creativity.

Table 2

*Spearman Correlations of the 24 Assessment Items*

<table>
<thead>
<tr>
<th>Domain (C)</th>
<th>Item</th>
<th>Spearman item correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge (C1) Domin</td>
<td>C1-1 item</td>
<td>.477</td>
</tr>
<tr>
<td>Comprehension(C2)</td>
<td>C1-2</td>
<td>.390</td>
</tr>
<tr>
<td></td>
<td>C1-3</td>
<td>.507</td>
</tr>
<tr>
<td></td>
<td>C1-4</td>
<td>.512</td>
</tr>
<tr>
<td></td>
<td>C2-1</td>
<td>.570</td>
</tr>
<tr>
<td></td>
<td>C2-2</td>
<td>.576</td>
</tr>
<tr>
<td></td>
<td>C2-3</td>
<td>.536</td>
</tr>
<tr>
<td></td>
<td>C2-4</td>
<td>.442</td>
</tr>
<tr>
<td>Comprehension(C2)</td>
<td>C3-1</td>
<td>.539</td>
</tr>
<tr>
<td></td>
<td>C3-2</td>
<td>.526</td>
</tr>
<tr>
<td></td>
<td>C3-3</td>
<td>.673</td>
</tr>
<tr>
<td></td>
<td>C3-4</td>
<td>.614</td>
</tr>
<tr>
<td>Analysis (C4)</td>
<td>C4-1</td>
<td>.476</td>
</tr>
<tr>
<td></td>
<td>C4-2</td>
<td>.580</td>
</tr>
<tr>
<td></td>
<td>C4-3</td>
<td>.584</td>
</tr>
<tr>
<td></td>
<td>C4-4</td>
<td>.539</td>
</tr>
<tr>
<td>Evaluation (C5)</td>
<td>C5-1</td>
<td>.663</td>
</tr>
<tr>
<td></td>
<td>C5-2</td>
<td>.509</td>
</tr>
<tr>
<td></td>
<td>C5-3</td>
<td>.572</td>
</tr>
<tr>
<td></td>
<td>C5-4</td>
<td>.699</td>
</tr>
<tr>
<td>Creativity (C6)</td>
<td>C6-1</td>
<td>.593</td>
</tr>
<tr>
<td></td>
<td>C6-2</td>
<td>.535</td>
</tr>
<tr>
<td></td>
<td>C6-3</td>
<td>.591</td>
</tr>
<tr>
<td></td>
<td>C6-4</td>
<td>.632</td>
</tr>
</tbody>
</table>
4.5 Linear Regression

Regressions are widely used to determine the associations between the outcomes of the experiment (posttest score) and a number of confounding variables (gender, major, age) in addition to the treatment (PBL) (McNamee, 2005). There was no significant difference in students mean age between the control and H-PBL group (20.2 and 20.26 respectively) so no further analysis was done on students’ age. The majority of the sample was female students (Figure 10). Most of the students were biology (43) and biochemistry (23 students) and just a few students were from other majors (14 students) (Figures 11, and 12). Test of regression assumptions indicated that normality was met (Figure 13), linearity was met (Figure 14) and homoscedastacity was met (Figure 15).

In the regression model, the post score assessment was considered as the dependent variable, PBL activities, gender and major were the predictors variables and the outcomes listed in Tables 3, 4, 5 and 6.

![Gender Frequencies](image)

*Figure 10. Gender frequencies in the H-PBL groups.*
Figure 11. Study fields distribution in the H-PBL group.

Figure 12. Study fields distribution in the control group.
Figure 13. Normality distribution met.

Figure 14. Linearity met.
Figure 15. Homoscedasticity met.

Table 3

Linear Regression Model Summary for Gender, Major and H-PBL

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R square</th>
<th>Adjusted R square</th>
<th>Std Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.358</td>
<td>.128</td>
<td>.082</td>
<td>2.70340</td>
</tr>
</tbody>
</table>

Table 4

Analysis of Variance Results of the Regression

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Regression</td>
<td>80.760</td>
<td>4</td>
<td>20.190</td>
<td>2.763</td>
<td>.034b</td>
</tr>
<tr>
<td>Residual</td>
<td>548.127</td>
<td>75</td>
<td>7.308</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>628.887</td>
<td>79</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Dependent Variable: Total_Post
b. Predictors: (Constant), Treatment (PBL), Gender, Major
Table 5

**Regression Coefficient of the Variables (Gender, Major, H-PBL)**

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>(Constant)</td>
<td>19.278</td>
<td>4.939</td>
<td>3.903</td>
</tr>
<tr>
<td></td>
<td>Major</td>
<td>-.097</td>
<td>.247</td>
<td>-.043</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>-.608</td>
<td>.765</td>
<td>-.087</td>
</tr>
<tr>
<td></td>
<td>PBL</td>
<td>1.747</td>
<td>.605</td>
<td>.312</td>
</tr>
</tbody>
</table>

a. Dependent Variable: Total_Post

Table 6

**Regression Correlation Matrix between Gender, Major, PBL and the Post Test Score**

<table>
<thead>
<tr>
<th>Pearson Correlation</th>
<th>Total Post test score</th>
<th>Major</th>
<th>Age</th>
<th>Gender</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Post</td>
<td>1.000</td>
<td>-.049</td>
<td>-.154</td>
<td>-.074</td>
<td>.308</td>
</tr>
<tr>
<td>Major</td>
<td>-.049</td>
<td>1.000</td>
<td>.164</td>
<td>-.159</td>
<td>.020</td>
</tr>
<tr>
<td>Gender</td>
<td>-.074</td>
<td>-.159</td>
<td>-.040</td>
<td>1.000</td>
<td>.000</td>
</tr>
<tr>
<td>PBL</td>
<td>.308</td>
<td>.020</td>
<td>.020</td>
<td>.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sig. (1-tailed)</th>
<th>Total Post</th>
<th>Major</th>
<th>Age</th>
<th>Gender</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Post</td>
<td>.</td>
<td>.333</td>
<td>.087</td>
<td>.258</td>
<td>.003</td>
</tr>
<tr>
<td>Major</td>
<td>.333</td>
<td>.</td>
<td>.072</td>
<td>.079</td>
<td>.430</td>
</tr>
<tr>
<td>Gender</td>
<td>.258</td>
<td>.079</td>
<td>.362</td>
<td>.</td>
<td>.500</td>
</tr>
<tr>
<td>PBL</td>
<td>.003</td>
<td>.430</td>
<td>.430</td>
<td>.500</td>
<td>.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>N</th>
<th>Total Post</th>
<th>Major</th>
<th>Age</th>
<th>Gender</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Post</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Major</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Gender</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
</tbody>
</table>
After testing the reliability of the assessment (Chronbach’s alpha), investigating the correlation between test items (spearman correlation) and excluding the possible effect of the confounding variables (gender and major) by linear regression, we can proceed to analyze the findings of this study.

4.6 Paired Samples Statistics

A paired t-test was conducted to compare the overall performance of the H-PBL and control group on two occasions - the pre and posttest. The resultant figures are captured in Tables 7 and 8, Figure 15. The effect size of the paired-sample t-test was calculated as following: Eta squared= \( \frac{t^2}{t^2+N-1} = \frac{(-30)^2}{(-30)^2+80-1} = 0.91 \)

According to Cohen (1988, 1992), the value .01 is considered a small effect size, .06 as a medium effect and value of at least 0.14 is considered a large effect.

Table 7  
*Comparing the Overall Mean for the Pre and Post Test Scores*

<table>
<thead>
<tr>
<th>Paired Samples Statistics</th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pre-test scores</td>
<td>3.9188</td>
<td>80</td>
<td>1.84433</td>
<td>.20620</td>
</tr>
<tr>
<td>Total post-test scores</td>
<td>12.6625</td>
<td>80</td>
<td>2.82145</td>
<td>.31545</td>
</tr>
</tbody>
</table>

Table 8  
*Descriptive Statistic of Paired Sample t-Test for Pre and Post Test Scores*

<table>
<thead>
<tr>
<th>Paired sample test</th>
<th>Mean</th>
<th>Std.Erorr Mean</th>
<th>Std.deviation</th>
<th>Sig.(2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Totalpre-total post</td>
<td>-8.74</td>
<td>.29</td>
<td>2.6</td>
<td>.000</td>
</tr>
</tbody>
</table>
Figure 16. Comparing the pre and post test gain scores for all study groups ($N = 80$, Eta squared $= .91$).

4.7 Independent t-Test

An independent-sample t-test was conducted to compare the pretest mean score to the posttest mean score between H-PBL ($N = 40$) and control group ($N = 40$). The outcome is presented in Tables 9, 10, and Figure 16. The effect size for independent-sample t-test:

$$\text{Eta squared} = \frac{t^2}{t^2 + (N_1 + N_2 - 2)}$$

$$\text{Eta squared of the pretest} = \frac{(1.51)^2}{(1.51)^2 + (78)} = 0.000$$

$$\text{Eta squared of the posttest} = \frac{(-2.855)^2}{(-2.855)^2 + (78)} = 0.09$$

Table 9

Descriptive Statistic of Independent Sample t-Test for Pre and Post Test

<table>
<thead>
<tr>
<th></th>
<th>Levene's Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
</tr>
<tr>
<td>Total Pre</td>
<td>Equal variances assumed</td>
<td>3.892</td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td>.151</td>
</tr>
<tr>
<td>Total Post</td>
<td>Equal variances assumed</td>
<td>.141</td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td>-2.855</td>
</tr>
</tbody>
</table>
Table 10
Independent t-Test Result Comparing the Mean Score of the Pre and Post Tests for the Two Study Groups

<table>
<thead>
<tr>
<th></th>
<th>Treatment</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total_Pre</td>
<td>Control</td>
<td>40</td>
<td>3.9500</td>
<td>2.07488</td>
<td>.32807</td>
</tr>
<tr>
<td></td>
<td>H-PBL</td>
<td>40</td>
<td>3.5875</td>
<td>1.60723</td>
<td>.25412</td>
</tr>
<tr>
<td>Total_Post</td>
<td>Control</td>
<td>40</td>
<td>11.8000</td>
<td>2.87741</td>
<td>.45496</td>
</tr>
<tr>
<td></td>
<td>H-PBL</td>
<td>40</td>
<td>13.5250</td>
<td>2.51394</td>
<td>.39749</td>
</tr>
</tbody>
</table>

Figure 17. Comparing students’ test scores on the two different occasions. The pretest eta squared = 0.000, the posttest eta squared = 0.09.

4.8 ANOVA on Gain Scores

Student gain score was chosen to be the independent variable in the one-way ANOVA in order to compare the performance of the two groups (H-PBL, N = 40 and control group, N = 40) on each level of the assessment. In addition, ANOVA is known to controls for the pretest score of the experiment. Gain score is calculated by subtracting the pretest score from the posttest.
score. When the reliability and the variance of the pre and posttest are different, the use of the
gain score reliability is high (Zimmerman & Williams, 1982, Rogosa et al., 1982; Overall &
Woodward, 1975). The homogeneity of variance was checked by using Levene’s test, the result
is represented in Table 11. None of sig. values is lower than .05, which means that the
homogeneity is met. The result of comparing the control and H-PBL group gain test score using
one-way ANOVA is presented in Tables 12 and 13, Figure 17.

The effect size was then calculated in the following way to further establish the findings:

Eta squared in one way ANOVA \( (\eta^2) = \frac{\text{sum of squares between group}}{\text{total sum of squares}} \)

\[ \text{Eta squared for total post C1} = \frac{0.05}{44.8} = 0.001 \]
\[ \text{Eta squared for total post C2} = \frac{0.003}{60.297} = 0.000 \]
\[ \text{Eta squared for total post C3} = \frac{0.028}{73.722} = 0.000 \]
\[ \text{Eta squared for total post C4} = \frac{2.628}{62.472} = 0.04 \]
\[ \text{Eta squared for total post C5} = \frac{7.503}{83.347} = 0.09 \]
\[ \text{Eta squared for total post C6} = \frac{14.45}{65.5} = 0.22 \]

Table 11

<table>
<thead>
<tr>
<th>Test of Homogeneity of Variances</th>
<th>Levene Statistic</th>
<th>df1</th>
<th>df2</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>gainC1</td>
<td>1.879</td>
<td>1</td>
<td>78</td>
<td>.174</td>
</tr>
<tr>
<td>gainC2</td>
<td>1.804</td>
<td>1</td>
<td>78</td>
<td>.183</td>
</tr>
<tr>
<td>gainC3</td>
<td>.584</td>
<td>1</td>
<td>78</td>
<td>.447</td>
</tr>
<tr>
<td>gainC4</td>
<td>9.075</td>
<td>1</td>
<td>78</td>
<td>.003</td>
</tr>
<tr>
<td>gainC5</td>
<td>.114</td>
<td>1</td>
<td>78</td>
<td>.737</td>
</tr>
<tr>
<td>gainC6</td>
<td>2.731</td>
<td>1</td>
<td>78</td>
<td>.102</td>
</tr>
</tbody>
</table>
## Table 12

**Descriptive Result Comparing the Gain Score of the Six Domains Between the Two Study Groups**

<table>
<thead>
<tr>
<th>Domain</th>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>control</td>
<td>40</td>
<td>1.9750</td>
<td>.80024</td>
<td>.12653</td>
</tr>
<tr>
<td></td>
<td>H-PBL</td>
<td>40</td>
<td>1.8650</td>
<td>1.04237</td>
<td>.16481</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>80</td>
<td>1.9250</td>
<td>.92470</td>
<td>.10338</td>
</tr>
<tr>
<td>Application</td>
<td>control</td>
<td>40</td>
<td>1.5125</td>
<td>.78027</td>
<td>.12337</td>
</tr>
<tr>
<td></td>
<td>H-PBL</td>
<td>40</td>
<td>1.7250</td>
<td>1.00480</td>
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Table 13

*Descriptive Analysis of Assessment Variance of the Six Domains*

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</table>

* Indicated significant result (P>0.05)
Figure 18. Comparing the six levels of the assessment gain scores between the control and the H-PBL groups.

4.9 Anecdotal Data Spring/Fall 2016

As a part of the microbiology laboratory evaluations, two questions were added to the H-PBL group. Only 35% of students left responses while the rest of the H-PBL (65%) sample didn’t leave responses. Some of the responses from H-PBL group are shown below:

The case studies were very fun and very useful. (Student 1)

The study cases were very interesting, I have learned so much. (Student 2)

The activities gives in this class are helpful and I like the pre/post assessment because the questions are important and not too detailed, I like how it is short answer instead of multiple choices. (Student 3)

The extra quizzes were fun and helpful, but the assessment is a bit long and I prefer scontron. (Student 4)

Love It, gave additional application to information, we were learning a lot. (Student 6)

the activities are very helpful especially it made me to read more about the new labs but sometimes it hard to answer. (Student 7)

The extra activities and pre/post assessment are fun and tie the information together, I believe a fill in the blank or scantron assessment would be better. (Student 8)
I like the study cases but I would prefer more multiple choice questions for the Pre/post assessment. (Student 9)

The extra assignments were useful; this assessment would be better if it was all fill-in the blank, however, it nice to see how much you learn. (Student 10)

I love the extra assignments, gave me an extra look at the background of some labs and taught me things I didn’t know, but prefer multiple-choice questions for the assessment. (Student 12)

I like the extra activities in the lab, it help solidify the concept and result in my head, I think multiple choice and matching would be better and easier, not easier material just format. (Student 13)

The activities were interesting of real life problems most of the time. (Student 14)

I like the idea of having pre&post assessment. I think it is a great way for us to see how we have improved. (Student 15)

I think the activities were fun and I enjoyed them. And the assessment was useful to see what we learned. (Student 16)
CHAPTER 5
DISCUSSION

The study results support the incorporation of problem-based learning (PBL) into traditional lecture-based learning. In this study, 30% of the curriculum was delivered in PBL format, while the rest was provided using the traditional lecture-based method, thus resulting in H-PBL.

The measurements in this study were conducted by assessing the responses to 24 short answer questions formulated by the researcher, each of which represented one level of the revised Bloom’s Taxonomy, which includes six domains (knowledge, comprehension, application, analysis, evaluation, creativity). The assessment showed good reliability (Cronbach’s alpha was 0.7- 0.8) (see Table 1). Additionally, each item in the assessment correlated well to its domain since none of the individual items had a correlation value of less than 0.3 (Fercketich, 1991; Nunnally, 1978). These values indicate that the questions on the pre/post assessments were reliable and measured the same target concept. The validity of the assessment was checked by Dr. Nathaniel C. Mills, a faculty member from Texas Woman’s University (TWU) in 2016 to confirm that the measurements made using the questions suited our goal. Moreover, students needed about 30-35 minutes of response time. Therefore, the instrument utilized in this study was considered to be reliable, valid, and practical.

This study was conducted during the long semesters (Spring 2016 and Fall 2016). At the beginning of each semester, the two study groups of Microbiology laboratory—control, meaning traditional laboratory-based students ($N = 40$); and H-PBL meaning hybrid problem-based students ($N = 40$)—were tested to evaluate their microbiology background using the pre-assessment. The results recorded in Tables 9 and 10 revealed that there were no statistically
significant differences in the pretest mean scores for the control ($M = 3.95, SD = 2.06$) and H-PBL groups ($M = 3.5875, SD = 1.59$), $p = .831$. In addition, the pretest exhibited a small effect size of $r = .000$. This implies that both groups started with the same measured experience in microbiology prior to take the course. At the end of the semester, the two groups responded to the same assessment, and a statistically significant difference could be observed in their posttest scores, for both the control ($M = 11.8, SD = 2.86$) and H-PBL ($M = 13.52, SD = 2.5$), $p = .000$ groups, and the posttest exhibited a large size effect of $r = 0.091$ (Figure 17).

Before analyzing the available data (pre/post assessment scores), a number of confounding variables (gender, major) were used to determine potential differences in the posttest scores between the two groups using linear regression. The results of the linear regression presented in Table 5 demonstrate that PBL activities were the significant predictor of the total posttest score, ($\beta = .312$, $t = 2.890$) $P<0.005$. While Major ($\beta = -.043$, $t = -.393$) and gender ($\beta = -.087$, $t = -.795$) were not significant predictors of the total posttest score. The regression equation is as follows: Predicted total post test score=19.28 + 1.747 (PBL)

Further, recalling the correlation matrix (Table 6), we can observe additional support for the stronger association between the H-PBL group and the posttest score with their Pearson’s $r = .308$ ($p < .001$), while gender $r = (-.074)$ and major $r = (-.049)$ were correlated negatively with posttest scores.

The results of the paired sample t-test analysis, comparing the overall student performance from the pretest to the posttest, revealed that there was a marked gain in the posttest scores over the pretest scores with $t (30) = 79, p < .000$ ($M = - 8.74375, SD = 2.59534$). The increase in the mean from the pretest ($M = 3.9, SD = 1.8$) to the posttest ($M = 12.66, SD = 2.8$) was 8.74 with a 95% confidence interval ranging from -9.32 to -8.16. The effect size of the
paired-sample t-test was 0.91, which is considered a large effect (Cohen, 1992). In addition, these results indicated that both the teaching styles (H-PBL and traditional lecture) positively enriched students’ experience in microbiology.

A one-way ANOVA between the groups using the gain scores of variances was conducted to explore the impact of incorporating PBL activities on students’ performance, as measured by pre/post assessment. Even though there were differences in the gain scores for all assessment constructs between the traditional lecture-based students and the H-PBL students, not all of them reached a statistically significant level (Table 13).

For the first three levels of Bloom, there were no statistically significant differences between the H-PBL and control group gain scores as determined by a one-way ANOVA. Construct 1 (knowledge), $F(1, 78) = .232, p = .632, r = .001$; Construct 2 (comprehension), $F(1,78) = .004, p = .951, r = 0.000$; Construct 3 (application), $F(1,78) = .028, p = .868, r = 0.000$. On the other hand, among the higher-level questions, Construct 4 representing the analysis level had statistically significant differences with $F(1, 78) = 4.012, p = .049, r = 0.04$. In addition, there were statistically significant differences in students’ performance at the evaluation and creativity levels, $F(1, 78) = 11.495, p = .001, r = 0.09$ and $F(1,78) = 23.432, p = .000, r = 0.22$, respectively. The results of calculating the effect size, which indicates the size of the differences between the groups, also confirmed the results. The first three levels showed a small effect size (0.000), while the three higher levels of analysis and evaluation domains represented small- and medium- effect sizes ($r = 0.04$ and $r = 0.09$, respectively). Also, questions on the creativity level indicated a large effect size ($r = .22$).

The statistical analysis of our study results indicate that there were no significant differences between the control and H-PBL students in terms of their performance on low-level
questions (knowledge, comprehension, and application). This corresponded with the results of a study conducted at Harvard by Thammasitboon et al. (2007) who also confirmed no significant differences on students’ theoretical knowledge among medical students taught using the PBL approach and the traditional lecture-based approach. Similar findings were also reported by other studies (Schmidt et al., 2006; Prince et al., 2005).

While no effect of the hybrid PBL approach could be observed on students’ basic knowledge in the current study, hybrid PBL students achieved better scores on high-level questions (analysis, evaluation, and creativity). This result is comparable to Zhang (2014)’s study where PBL nursing students performed better than traditional lecture nursing students on the high-level questions, which required analysis and knowledge application.

Our overall results matched a number of other studies that found positive effects of PBL on students’ performance in high-level exam questions compared to traditional lecture-based students. Blake et al (2000) used the United States Medical Licensing Examination (USMD) step 1 (test the basic knowledge using multiple-choice questions) and step 2 (test clinical science using essay questions) to investigate the effect of PBL on medical students. After experiencing PBL, no significant difference was found in the students’ response to the step 1 exam while PBL students recorded a significantly higher score on the step 2 exam. Several other studies also found that while implementation of PBL in the curriculum did not affect knowledge acquisition (Khoshnevisasl et al., 2014), it had a positive effect on critical thinking (Şendağ & Odabaşı, 2009; Thammasitboon et al. 2007) and student attitude (Khan et al., 2007).

However, the effect of H-PBL on student basic knowledge in our study contradicts the results of other studies that reported that PBL students gained lower scores than traditional lecture-based students on basic knowledge (Johnston et al., 2009; Miller, 2003; Dochy et al.,
It also contrasted with other studies, which found that PBL students gained more basic knowledge than conventional curriculum students (Zhang, 2014; Meo, 2013; Gurpinar et al., 2005).

The key feature in this study, however, has its use in a microbiology course, which had not previously been done.

There are a number of explanations about the variations in the PBL outcomes based on differences in experimental design, duration of the study, and PBL model (pure or hybrid). Most importantly, the manner of assessing or measuring PBL outcomes highly affects the final results (Dochy et al., 2003, Dochy et al., 1999).

As mentioned earlier, the instrument used in this study consisted of short answer questions that required a response ranging from one word to a couple of sentences. The level of these questions ranged from easy to difficult according to the revised Bloom’s taxonomy (Figure 5) to cover basic students’ knowledge, their ability to apply this knowledge, and their overall understanding. For the higher levels, the questions measured students’ ability to analyze a concept, evaluate a given situation, and generate a solution for a case in their own words.

There were common format of instruments utilized by the studies that did not report the positive effect of PBL, which mostly used a knowledge-based instrument in the form of true/false or multiple-choice questions (MCQ) (Rideout et al., 2002; Adelstein & Carver, 1994; Eisenstaedt et al., 1990). Using those types of instrument contradicts PBL aims, and thus, it should not be used to measure higher cognitive skills (Crowe et al., 2008). Dochy et al. (2003) stated, “the better an instrument is capable of evaluating students’ skills, the larger the ascertained effects of PBL” (p. 547).
Additional studies that have reported the positive effects of PBL most often use mixed skills instruments in the form of short answers, essay questions, or study cases (Rich et al., 2005; Tamblyn et al., 2005; McParland et al., 2004; Richards et al, 1996), which similar to the one used in this study. Additionally, O'Neill (1998) reported that essay questions are more appropriate to assess PBL after he examined various methods to evaluate PBL among dental students.

Another reason that might affect the effectiveness of PBL on students’ academic achievements can be the amount of time that the student is exposed to PBL. Schwartz et al. (2009) claimed that time was the major factor influencing study success. This finding was also supported by a retrospective study from South Africa which compared the performance of students who had been trained using PBL for four years in doctor training with students who had been trained traditionally, which found that PBL students were superior to the traditional students in term of their academic achievement (Iputo & Kwizera, 2005). While another study that observed the effects of PBL for a period of only five weeks on biotechnology students and showed a negative effect on their academic achievement compared to traditional lecture-based students (Cheaney & Ingebritsen, 2005).

Third, the form of PBL, whether pure or hybrid, also has an impact on the final result. The current study used the H-PBL format with lessons delivered in PBL representing 30% of the course. Most of the studies in relation to this topic used pure PBL design so that the course would be either in PBL format or lecture-based format. Students who experienced the pure PBL format reported their desire to have part of the curriculum in the traditional form (Haghparast et al., 2007)
Very few studies have discussed the value of H-PBL format in cases where completely transforming the class from the traditional format to pure PBL format appears difficult, which was the case in this study. To the extent of our knowledge to date, only four studies so far have evaluated the effectiveness of an H-PBL lecture courses instead of a lecture-based courses (Carrió et al., 2016; Chilkoti et al., 2016; Lian and He, 2013; Callis et al., 2010). These previous studies reported the positive impact of H-PBL on basic student skills (Callis et al., 2010), long-term knowledge (Carrió et al., 2016), and problem-solving skills (Lian & He, 2013), which is consistent with our results.

In addition to the pre/post assessment data, students’ performance in their final laboratory exam was considered. Both control and H-PBL group exhibited similar average scores on their final exam (82.1 and 81.1 respectively), which demonstrates that H-PBL did not have an effect on the final laboratory exam score. Two reasons may explain the result: first, in the laboratory exam, there is often a practical section based on laboratory skills, techniques, and procedures, which is testing something different from what PBL is focused on. Second, the level of the final exam questions also might explain this result; most of the questions in the final laboratory exam needed only low levels of thinking and were not written to evaluate the deeper understanding and higher cognitive thinking that the PBL students might have developed. This finding was consistent with the findings of the study by Pourshanazari et al. (2013) on the effects of PBL in the medical field but it was in contrast to the Lian, (2013), Tandogan & Orhan (2007) and Iputo & Kwizera (2005) studies which reported improvement in student academic achievement after applying PBL. In a study conducted by Lord and Baviskar (2007) science exams questions were classified according to Bloom’s Taxonomy they found that found that 94% of exam questions tested only low level skills and about 6% tested high level skills.
Beside the quantitative data, qualitative data was collected to evaluate students’ satisfaction about their experience with H-PBL. Two questions were added to the departmental lab instructor evaluation asking students in the H-PBL section to provide feedback on their experiences in using study cases over a four-month period in a traditionally structured undergraduate microbiology laboratory. The majority of the students reported positive views about the study cases and described how it increased their passion to learn. Our finding was consistent with Chilkoti et al. (2016) and Lian (2013) who found that H-PBL enhanced students’ learning experience satisfaction that is also in line with other studies (Abbey et al., 2016; Tandogan, & Orhan, 2007).

5.1 Conclusions, Limitations, and Recommendations

This study compared students in the H-PBL group (30% PBL) with traditional-lecture based student group by using an instrument-designed based on Bloom’s taxonomy. H-PBL students performed better than traditional students in the area of analysis, evaluation, and creativity depending on their scores on the three high-thinking domains that is needed for science students for their careers.

There was no noticeable difference between control and H-PBL students in theoretical knowledge and basic skills based on their performance on pre/post assessment, which was created based on the revised Bloom’s Taxonomy. Some previous research has also indicated that PBL students had ultimately lower basic knowledge than did traditional lecture-based students, and using the PBL in hybrid format might overcome this problem because students can get the benefit of both PBL and traditional lecture-based format.
Using the appropriate assessment is an important tool for measuring the full effect of H-PBL. The assessment here was designed specifically for this study, and it had good reliability, validity, and practicability, implying that it can be used as a model to assess PBL in microbiology laboratory for future studies.

5.2 Limitations/Recommendations

This study did not assess long-term outcomes but only measured the short-term gain of H-PBL result for one semester. As mentioned earlier, most research reported that PBL could promote long-term knowledge better than the traditional lecture method (Pourshanazari et al., 2013; Carrió et al., 2016). Thus, conducting a long-term study is recommended to supplement this study data.

Students in this study were exposed to H-PBL for a period of one long semester, while other studies showed that the results improved when the amount of time spent was increased. Indeed, experiencing PBL for a longer time is recommended.

The choice of implementing 30% PBL in a traditional curriculum was made since the incorporation of PBL into the traditional laboratory was not welcomed to avoid this resistance, we minimized the PBL activities to cover only six labs that represent about 30% of the course. Increasing PBL time to 35% or 50% may enhance its impact on the academic result. A side goal, however, was to increase the openness of other microbiology lab teachers to the idea of adopting PBL by providing statistical evidence demonstrating its potential gains for higher-order thinking skills.

In order to control for the “teachers’ effect”, this study was restricted to only two groups who were taught by the same instructors; therefore, we used a relatively small sample size.
Although the sample taken fulfilled the objective of this study, conducting this study with a larger sample size taught by multiple instructors to control for the teacher effect could lead to alternate conclusion.

Additional future research to determine the value of compromised H-PBL into life science would also provide useful data.
APPENDIX A

INFORMED CONSENT FORM
December 15, 2015

Rudi Thompson
Student Investigator: Najwa Alharbi
Department of Biological Sciences
University of North Texas

RE: Human Subjects Application No. 15-378

Dear Dr. Thompson:

In accordance with 45 CFR Part 46 Section 46.101, your study titled “The Effect of Project Based Learning in Contrast to Current Laboratory Manual Based Learning within the Microbiology Laboratory” has been determined to qualify for an exemption from further review by the UNT Institutional Review Board (IRB).

Enclosed are the consent documents with stamped IRB approval. Please copy and use this form only for your study subjects.

No changes may be made to your study’s procedures or forms without prior written approval from the UNT IRB. Please contact Jordan Harmon, Research Compliance Analyst, ext. 4643, if you wish to make any such changes. Any changes to your procedures or forms after 3 years will require completion of a new IRB application.

We wish you success with your study.

Sincerely,

Chad Trulson, Ph.D.
Professor
Chair, Institutional Review Board

CT: Jh
University of North Texas Institutional Review Board

Informed Consent Form

Before agreeing to participate in this research study, it is important that you read and understand the following explanation of the purpose, benefits and risks of the study and how it will be conducted.

Title of Study: The effect of project based learning in contrast to current laboratory manual based learning within the Microbiology laboratory.

Investigator: Najwa Alharbi, University of North Texas (UNT) Department of Biological Sciences.

Purpose of the Study: You are being asked to participate in a research study, which involves collection of assessments that will be used to develop problem based learning laboratories in Microbiology.

Study Procedures: You will be asked to respond to a brief pre-course assessment that will take about 30 to 45 minutes of your time, as well as a post-course assessment at the end of the course. There will be no personal information collected, only demographic data.

Foreseeable Risks: There are no foreseeable risks involved in this study.

Benefits to the Subjects or Others: This study may not directly benefit you, but we hope to learn more about how problem based learning enables educational development in Microbiology laboratories.

Compensation for Participants: None

Procedures for Maintaining Confidentiality of Research Records: The survey responses are anonymous.

Questions about the Study: If you have any questions about the study, you may contact Najwa Alharbi at najwaalharbi@unt.edu or Dr. Rudi Thompson, Supervising Investigator for the study at Ruthanne.thompson@unt.edu

Review for the Protection of Participants: This research study has been reviewed and approved by the UNT Institutional Review Board (IRB). The UNT IRB can be contacted at (940) 565-4643 with any questions regarding the rights of research subjects.

Office of Research Integrity & Compliance
University of North Texas
Last Updated: July 11, 2011

Page 1 of 2
Research Participants' Rights:

Your signature below indicates that you have read or have had read to you all of the above and that you confirm all of the following:

- Najwa Alharbi has explained the study to you and answered all of your questions. You have been told the possible benefits and the potential risks and/or discomforts of the study.
- You understand that you do not have to take part in this study, and your refusal to participate or your decision to withdraw will involve no penalty or loss of rights or benefits. The study personnel may choose to stop your participation at any time.
- Your decision whether to participate or to withdraw from the study will have no effect on your grade or standing in this course.
- You understand why the study is being conducted and how it will be performed.
- You understand your rights as a research participant and you voluntarily consent to participate in this study.
- You have been told you will receive a copy of this form.

Printed Name of Participant

Signature of Participant ___________________________ Date ______________

For the Investigator or Designee:

I certify that I have reviewed the contents of this form with the subject signing above. I have explained the possible benefits and the potential risks and/or discomforts of the study. It is my opinion that the participant understood the explanation.

Signature of Investigator or Designee ___________________________ Date ______________

Office of Research Integrity & Compliance
University of North Texas
Last Updated: July 11, 2011

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APPENDIX B

MICROBIOLOGY LAB SYLLABUS (BIOL2024)
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<tr>
<td>Microscopes (Hay infusion)</td>
<td>Lab 3</td>
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<tr>
<td>Culture media preparation</td>
<td>Lab 2</td>
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<tr>
<td>Inoculation of media, Aseptic techniques</td>
<td>Lab 3</td>
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<tr>
<td>Labor Day-No labs Monday or Tuesday</td>
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<tr>
<td><strong>Quiz # 1</strong></td>
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<tr>
<td>Bacterial Nomenclature, Colony and Cell morphology</td>
<td>Lab 4</td>
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<tr>
<td>Stains: Smear Preparation, Simple Stain</td>
<td>Lab.6, 7</td>
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<td>Negative Stain</td>
<td>Lab 5</td>
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<td>Gram stain</td>
<td>Lab 8</td>
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<td>Spore Stain</td>
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<tr>
<td>Acid Fast Stain</td>
<td>Lab 10</td>
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<td><strong>Quiz # 2</strong></td>
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<td>Environmental influences: Effects of Temperature</td>
<td>Lab 11</td>
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<tr>
<td>Oxygen tolerance</td>
<td>Lab 13</td>
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<td>Environmental influences</td>
<td>Lab 13</td>
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<td>Growth of Anaerobes</td>
<td>Lab 13</td>
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<td>Microbial Interrelationships</td>
<td>Lab 26</td>
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<td>Commensalism</td>
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<td>Environmental Influences: Lethal Effect of UV</td>
<td>Lab 12</td>
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<td>Catalase test</td>
<td>Lab 13</td>
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<tr>
<td>Environmental influences: pH, Osmolarity</td>
<td>Lab 14, 15</td>
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<td>The growth of microorganisms: Bacterial population count</td>
<td>Lab 22</td>
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<td>Antibiotic-producing organisms</td>
<td>Lab 17</td>
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<td><strong>Quiz # 3</strong></td>
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<tr>
<td>Microbial survey: Cyanobacteria, Protozoa, Algae</td>
<td>Lab 21</td>
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<tr>
<td>Microbial Survey: Fungi</td>
<td>Lab 20</td>
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<tr>
<td>Fungi cont, lichens</td>
<td>Lab 20</td>
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<td>Review for practical</td>
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<td><strong>PRACTICAL EXAM # 1</strong></td>
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<tr>
<td>Controlling Microorganisms</td>
<td>Lab 18</td>
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<td>Antiseptic and Disinfectants</td>
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<td>Antibiotics, antimicrobials</td>
<td>Lab 19</td>
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<td>Genetics of microorganisms: Conjugation</td>
<td>Lab 28</td>
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<td>Genetics of microorganisms: Transformation</td>
<td>Lab 27</td>
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<td>Viruses: Bacteriophages</td>
<td>Lab 29</td>
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<td>Bacteriological Examination of water:</td>
<td>Lab 24</td>
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<td>- Membrane Filtration, MPN, Colisure Test</td>
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<td><strong>Quiz # 4</strong></td>
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<td>Oxidase test: Fermenters/Non-fermenters</td>
<td>Lab 13</td>
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<td>Biochemical test: Starch test</td>
<td>Lab 34</td>
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<tr>
<td>Identification of Enterobacteria: Enteropluri</td>
<td>Lab 35</td>
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<tr>
<td>Biochemical Test: IMViC, Sugar Fermentation Tests, Motility (SIM)</td>
<td>Lab.31, 32, 33</td>
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<td><strong>Unknown organisms assigned</strong></td>
<td>Lab 36</td>
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<tr>
<td>Identification of Unknown Bacteria</td>
<td>Lab 36</td>
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<td>Bacterial Count of Food and Soil</td>
<td>Lab 23</td>
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<td>Microorganisms and Human Diseases: Epidemiology</td>
<td>Lab 25</td>
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<td>Microbial symbiosis</td>
<td>Lab 26</td>
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<td>Finish all labs</td>
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<td><strong>Unknown report due</strong></td>
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<tr>
<td>Thanksgiving- No labs Wednesday or Thursday</td>
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<tr>
<td><strong>PRACTICAL EXAM # 2</strong></td>
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Case study #1: Gram stain

-Rasha is a graduate student in the genetic lab. She ordered a specific strain of *Basillus sp*. Two weeks later, she received the bacteria plate, but she wasn’t sure if she got what she ordered. Before she went further in her project, she did a quick test of the bacteria sample. She got the following image under the light microscope:

![Image of bacteria sample](image)

-What kind of technique did she use?

-How can you explain the result she got?

-Do you think she can continue working on her project by using this bacteria sample? Why or why not?
Case study #2: Microbial amplification

Multiples Mega Multiples of Microbes

- Can you imagine how wealthy you would be if you put a penny in the bank and it doubled in value every single day? What if its value doubled several times a day? Could you count that high? At what point would you be a millionaire? A billionaire?

- Can you apply this theory into microbe population? Provide multiple methods to estimate the microbe number in culture?

- How can you demonstrate that “microbes eat”? Explain your hypothesis?
Antibiotic Resistance: Can We Ever Win?

Katelyn was excited to start her summer job in her microbiology professor’s research laboratory. She had enjoyed Dr. Johnson’s class, and when she saw the flyer recruiting undergraduate lab assistants for the summer, she had jumped at the opportunity. She was looking forward to making new discoveries in the lab.

On her first day, she was supposed to meet with Dr. Johnson to talk about what she would be doing. She knew the lab focused on antibiotic resistance in *Staphylococcus aureus*, especially MRSA (methicillin-resistant *S. aureus*).

She still remembered the scare her family had last year when her little brother got so sick. He’d been playing in the neighborhood playground and cut his lip when he fell off the jungle gym. Of course he always had cuts and scrapes—he was a five-year-old boy! This time though his lip swelled up and he developed a fever. When her mother took him to the doctor, the pediatrician said the cut was infected and had prescribed cephalothin, an antibiotic related to penicillin, and recommended flushing the cut regularly to help clear up the infection.

Two days later, Jimmy was in the hospital with a fever of 103°F, coughing up blood and having trouble breathing. The emergency room doctors told the family that Jimmy had developed pneumonia. They started him on IV antibiotics, including ceftriaxone and nafcillin, both also relatives of penicillin.

It was lucky for Jimmy that one of the doctors decided to check for MRSA, because that’s what it was! MRSA is resistant to most of the penicillin derivatives. Most cases of MRSA are hospital-acquired from patients who are already susceptible to infection, but the ER doctor explained that community-acquired MRSA was becoming more common.

The doctor then switched the treatment to vancomycin, a completely different kind of antibiotic, and Jimmy got better quickly after that.

Katelyn had dropped Jimmy off at swimming lessons just before coming to work at the lab. As she waited in the hallway for Dr. Johnson, she hoped that she would be at least a small part of helping other people like Jimmy deal with these scary resistant microbes. She was surprised when the professor burst out of the lab, almost running into her.
“Hi Katelyn, I’m really sorry but I have to run to a meeting right now—they sprung it on me last minute. There are a bunch of plates in the incubator right now that need their zones of inhibition measured. I’ll be back in a few hours,” Dr. Johnson said as he rushed down the hallway with a stack of folders.

Katelyn dug out her old lab notebook to look up what she was supposed to do. She found the lab where she and her fellow students had examined the antimicrobial properties of antibiotics using the Kirby-Bauer disk diffusion technique. Looking at the plates Dr. Johnson had told her about, she saw they had all been “lawned,” or completely coated with microbes to make a thick hazy layer over the agar surface. She could also see paper disks with letters on them, and some of the disks had clear zones around them where the microbe had been inhibited (Fig. 1).

Questions (see figure#1 in the following page)

1. What do you think the experimental question is?

2. Which antibiotics where most effective against *S. aureus*? Against MRSA?

3. When comparing the antibiotics effective against both, were there differences in effectiveness?
Plate 1. 

Plate 2. 

Plate 3. 

Figure 1. Agar plates of *S. aureus* or MRSA lawns with antibiotic disks placed on them.
Case Study #3: Lethal Effect Of Ultraviolet Light

When we think of keeping water clean, we usually think of filtration and chlorination. As the case below illustrates, these common techniques are sometimes inadequate to the task. Study the details of the case below, and use your knowledge of the effect of UV radiation to answer the questions that follow.

Gastrointestinal Outbreak Traced to interactive Fountain-New York, March 2006

The popular interactive water fountain, or "sprayground" at Seneca Lake State Park closed for the reminder of the summer on August 17, 2005, after the New York State Health Commissioner announced that an out break of cryptosporidiosis had been traced to the park. Cryptosporidiosis results from ingesting water contaminated with the protozoan Cryptosporidium parvum. Symptoms include diarrhea, vomiting, fever, and abdominal cramp. The sprayground itself an 11,000-squar-foot deck with hundreds of individual water jets, spouts, and hoses. After being sprayed into the air, water flows back into a holding tank below the play area before being recycled through the jets once again. This type of water playground has become immensely popular because even small children can play there without the risk of drawing associated with swimming pools. Unfortunately, the design of the Seneca Lake water playground allowed contaminants (e.g., vomit, feces, and dirt) to wash into the water-holding tanks supplying it. Testing revealed the presence of Cryptosporidium in those water tanks. Even though the water in the tanks was filtered and chlorinated, Cryptosporidium is small enough to pass through a filter and is also resistant to chlorine. Until methods could be implemented that would insure the well-being of patrons, the water park remained close.

Estimates of the number of cases of cryptosporidiosis traceable to the Seneca Lake sprayground ranged as high as 3800 people spread across 37 counties; fortunately, no fatalities were recorded. The total could have been even higher had the park not been shut down in mid-August. Although Cryptosporidium is resistant to chlorine, it is susceptible to ultraviolet (UV) light. Therefore, to prevent a recurrence of cryptosporidium, the New York State department of Health required that recirculated water in interactive fountains be disinfected using UV light. Installation of a donated $65,000 UV system allowed the park to reopen the following summer. Ultraviolet disinfection of water has long been used in Europe, but New York’s 2006 ultraviolet disinfection requirements were the first in the United state.
Questions:

1- In addition to having little penetrating power, the effectiveness of ultraviolet light diminishes greatly as the distance between the light and the surface to be treated increases. How would these two facts affect the design of a water disinfection system?

2- Even though UV treatment of water is generally more effective than chlorination, chlorination is still commonly used because of its residual effect (the antimicrobial effect that remains after water has been treated). Why is the residual effect of water chlorination so important?
“Keep hot foods hot and cold water foods cold” is a golden rule in food safety, and we are in the habit of using appliance like refrigerators, freezers, and heat lamps to help us accomplish this goal. However, as anyone who has ever tried to cool drinks in a frigid stream can tell you, Mother Nature often provide her own refrigeration. Read the study below and use your knowledge of the effects of temperature on bacteria to answer the questions that follow.

Out Break Of Gastroenteritis Associated With Consumption Of Alaskan Oysters-Multiple State, 2004

A Nevada resident who had just returned home from a cruise that sailed on Prince William Sound in July 2004 was struck by gastrointestinal distress so severe that medical intervention was required. Laboratory tests for this patient indicated the presence of *Vibrio Parahaemolyticus*, a pathogenic bacterium known to cause gastroenteritis. Infection usually occurs through consuming raw or undercook shellfish, particularly oysters. In this case, the patient’s illness began three days after eating raw oysters obtained from Prince William Sound.

Further investigation by the epidemiology section of the Alaska Division of Public Health revealed that a total of 45 people had developed watery diarrhea, along with various other gastrointestinal symptoms, beginning within two days of consuming raw oysters collected from Alaskan waters. Stool samples provided by eight patients all contained *V. Parahaemolyticus*. However, the discovery of this bacterium was puzzling because *V. Parahaemolyticus* requires a minimum water temperature of 16.5 °C to survive, and the waters of Prince William Sound have historically been colder than that.

Inspectors from the U.S Food and Drug Administration (FDA) investigated disinfection and food-handling practices aboard the cruise ship and obtained food and water samples for laboratory testing. They also assessed the oyster farm that had supplied the suspect oysters. When samples of oyster, water, and sediment were retrieved for analysis, two water samples, one sediment sample, and six oyster samples were culture-positive for *V. Parahaemolyticus*.

Because it requires a minimum temperature of at least 16.5 °C to grow, *V. Parahaemolyticus* is considered a mesophile. Historically, Alaskan waters have been too cold for the bacterium to thrive, and people have been too cold for the bacterium to thrive, and people
have routinely eaten raw oyster without concern for their safety. But due to the warming of the waters of the Prince William Sound, *V. Parahaemolyticus* spreads from its usual habitat to an area more than 900 kilometers further north, where it contaminated the oyster and cause the illness. This incident led to the closure of seven-oyster farm in Alaska pending further investigation. In addition, as a result of this case, testing for *V. Parahaemolyticus* is now routine throughout Alaska, and many oyster farmers have developed a new practice: when sea temperature approach 15°C, baskets of oysters are lowered to the colder water 100 feet below the surface to rid them of bacteria.

Questions:

Explain the following observations from the last 15 years:

- In cool, mountainous areas of South America, Africa, and Asia, a dramatic rise in the number of cases of malaria (carried by Anopheles mosquitos) has been seen.

- In London, the number of respiratory infections normally seen during the winter months have decreased.
Case study #5: epidemic

**Hunting the Ebola Reservoir Host**

**The Cycle Starts Again**

It was a hot day in August in a small village near Kikwit, Zaire, and Dr. Mombutubwa had another patient who was severely ill. With a note of resignation in his voice, he told his nurse: “I don’t think she’ll make it past the next couple of days.” The telltale red pinprick spots of blood had started to appear on the patient’s arms, and her eyes were red and blood-filled. Since the outbreak began in early July it was mostly women who came to see him with such an ailment. They generally complained of flu-like symptoms (headache, fever, muscle pain, sore throat) followed closely by stomach pain, vomiting, and diarrhea, which sometimes progressed to the bruising and hemorrhaging that he was seeing in his current patient. He knew there was little that could be done.

Dr. Mombutubwa turned his thoughts to what life in his village was like when it was not burdened by epidemics. Women stayed in the village, tending to the house, preparing food, and caring for the children. If the family had a farm, it was the women’s responsibility to tend to the crops, removing weeds and fending off rodents, birds, and insects that found the crops appealing. Often, the women gathered together to fetch water at a local well. The men headed out every morning into the forest, machete in hand, to hunt wild animals. They returned home in the evening with their quarry slung over their shoulders, often with blood on their hands and body. They would then proceed to carve up the carcass, distributing the meat among them. The men were especially jubilant when they returned with a butchered ape, whose body parts were used in
When bats were plentiful, men used shotguns to kill them. Women of child-bearing age were forbidden from eating bats, but they were happy to remove the shotgun bullets by hand to prepare the meat for their husband, children, and post-menopausal kin. The animals were barbecued over a fire and feasted on. Life continued on in this way and the people of Dr. Mombutubwa’s village seemed happy with their daily routines.

In the years that Dr. Mombutubwa had practiced medicine, he had seen a few outbreaks of this disease that once again threatened his village. He now knew that this disease was called Ebola, that it was caused by an RNA virus, and that it killed people. He had encountered Ebola several times and having worked with colleagues who came to help stop the spread of the disease during outbreaks, he was now an expert at recognizing its symptoms, diagnosing it despite the similarity of its symptoms to other viral diseases, and acting swiftly to contain the epidemic. He had first seen an outbreak when he was a boy, and he had wondered at the rapidity with which the disease decimated his village and disrupted daily life. So many people died, and the villagers became afraid of one another.

They stopped trading, they stayed inside their houses, and village life ground to a halt. Instead of tending to their corn or rice crops and their families, the women were consumed with cleansing preparations for funerals in which relatives of the deceased dressed the body of the dead, preparing it for the afterlife. When epidemics ended, there were never any traces of the disease in the village; it was as though the virus had disappeared. People returned to their daily activities, but once large families only had a few remaining members, since so many had succumbed to the disease.
Consulting the Disease Detectives

Joe Mackey was suddenly woken by the sound of his home phone ringing. “Who could possibly be calling at such an early hour?” he thought to himself. It was the Centers for Disease Control and Prevention (CDC) in Atlanta, Georgia, where Joe worked for the Epidemiology Intelligence Service (EIS). The EIS was often deployed around the world to help control epidemics.

Joe was on a plane the next morning to join Dr. Mombutubwa in his efforts to stop the spread of Ebola. The trip took over 30 hours, giving him plenty of time to organize his thoughts about this situation:

Humans must not be the normal host for the Ebola virus. The virus is too aggressive, killing all potential hosts,...

Since the rest of Dr. Mombutubwa report is missing, can you help to solve the mystery of Ebola virus by answering the following Questions:

. What are the possible points of contact that allow the transmission of Ebola between villagers during the epidemic?

. Ebola epidemics recur sporadically

  - How is this statement evidence that the virus can live in species other than humans? If the virus could only live in humans, might an epidemic recur?

  - In between epidemics, what is the virus “doing”? How is it replicating and being maintained? How does this other species...
APPENDIX D

PRE/POST ASSESSMENT
-Fill in the blank:

1. ………………….. is the shortest distance between two points on a specimen that can still be distinguished by the observer or camera system as separate entities.

2. …………………. is a complex polysaccharide derived from seaweed; it is used as a solidifying agent in culture media

3. ………………is the temperature that best suits the growth of a specific organism.

4. ………………..is the science that deals with when, where and how diseases occur.

Answer the following questions:

5. How do you determine what temperature is the optimal temperature for an organism?

6. Why are bacteria that form spores more resistant to UV exposure?

7. Using only a simple stain, what three things can you determine about bacteria?

8. What is the difference between selective and differential media?

9. Clarify why it is often important to know not only what types of bacteria are in a sample, but also how many of them are present.

10. How would you demonstrate if media is sterile?

11. From what you know about oil’s physical characteristics, why is oil needed for use in the light microscope when using the 100x objective?

12. In term of acidity and alkalinity, how does a negative stain work?

13. Why do you think bacteria have to be grown (cultured) in the laboratory on artificial culture media?
14. What explanation do you have for the use of salt and sugar to preserve foods in the food industry?

15. In which step of a Gram stain do lipids dissolve within the cell wall?

16. If you find your subcultures had no growth after incubation for 48 hours, what are possible errors that could have occurred?

17. Do you think it is good or bad to eat yogurt while you are on antibiotics? Explain.

18. Scientists have engineered a gram-positive bacterium to express a polysaccharide-rich outer capsule. How would this affect the Gram stain of the engineered organism?

19. How would you explain the following fact: most viruses that infect bacteria have tails, whereas most viruses that infect animals and plants do not.

20. What are the pros and cons of using bacterial transformation in biotechnology?

21. How would you develop a method to test the sweetness of food by using microbes?

22. When using a general media to grow bacteria, fungi often act opportunistic and grow on the media as well. What steps would you recommend to limit a sample to bacterial growth only?

23. On a field trip, your instructor asks each of you to take a soil sample to the lab and isolate antibiotics from these samples. Can you propose a method to isolate and test a new antibiotic?

24. What kind of fruit can you add to a loaf of bread to make it last longer? Explain your hypothesis.
APPENDIX E

PRE/POST ASSESSMENT RUBRIC
<table>
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<th>Bloom’s level</th>
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<th>0.5</th>
<th>1</th>
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<tr>
<td>Knowledge (C1)</td>
<td>Student fails to recall the answer</td>
<td>Student recalls a part of the correct answer</td>
<td>Student sufficiently recalls the right answer</td>
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<tr>
<td>Comprehension (C2)</td>
<td>Student fails to provide demonstrating for understanding</td>
<td>Student provides incomplete explanation of facts</td>
<td>Student provides complete description of facts</td>
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<tr>
<td>Application (C3)</td>
<td>Student fails to apply the theoretical concept to practical situation</td>
<td>Student does not sufficiently apply knowledge to practical situation</td>
<td>Student accurately illustrates and applies their knowledge to practical situation</td>
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<tr>
<td>Analysis (C4)</td>
<td>Student misinterprets the statement</td>
<td>Student offers an incomplete interpretation of the statement</td>
<td>Student accurately interprets the statement</td>
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<tr>
<td>Evaluation (C5)</td>
<td>Student fails to identify the result and reasons</td>
<td>Student justifies results but not the relevant reasons.</td>
<td>Student justifies results or procedures, and explains reasons.</td>
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<tr>
<td>Creativity (C6)</td>
<td>Fail to solve a new case using known concept</td>
<td>Combine concepts to create an original idea</td>
<td>Combine concepts to create an new idea</td>
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REFERENCES


