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EFFICACY OF PROBLEM BASED LEARNING IN A HIGH
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EFFICACY OF PROBLEM BASED LEARNING IN A HIGH SCHOOL SCIENCE CLASSROOM

By

James Ryan Rissi

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
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ABSTRACT

EFFICACY OF PROBLEM BASED LEARNING IN A HIGH SCHOOL SCIENCE CLASSROOM.

By

James Ryan Rissi

At the high school level, the maturity of the students, as well as constraints of the traditional high school (both in terms of class time, and number of students), impedes the use of the Problem-based instruction. But with more coaching, guidance, and planning, Problem-based Learning may be an effective teaching technique with secondary students.

In recent years, the State of Michigan High School Content Expectations have emphasized the importance of inquiry and problem solving in the high school science classroom. In order to help students gain inquiry and problem solving skills, a move towards a problem-based curriculum and away from the didactic approach may lead to favorable results.

In this study, the problem-based-learning framework was implemented in a high school Anatomy and Physiology classroom. Using pre-tests and post-tests over the material presented using the Problem-based technique, student comprehension and long-term retention of the material was monitored. It was found that Problem-based Learning produced comparable test performance when compared to traditional lecture, note-taking, and enrichment activities. In addition, students showed evidence of gaining research and team-working skills.

To Betsy, Jenna, and Jackson. I love you and I can't thank you enough for your understanding. You inspire me.

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What problems does a High School Science Teacher Face?

We live in a rapidly changing world. For educators, this truth presents new and frustrating problems. The infiltration of the internet and dynamic ways in which humans share information are changing the nature of the workforce for which educators are preparing students. Economies that were formerly industrial and demanded a hands-on "skills based" workforce are now morphing into information-based economies that demand higher levels of education, and more fundamentally, a greater degree of problem solving skills. And public school teachers are being asked to get all students to this higher degree of problem solving skills than ever before with the same basic system that has been used traditionally since the industrial revolution. Schools are still set up to produce students that can memorize facts, can absorb information and regurgitate factoids, but have no real skills when it comes to applying their knowledge to real world problems.

The problem facing science educators was neatly surmised by the popular scientist Carl Sagan when he quipped

> "We've arranged a civilization in which the most crucial elements profoundly depend on science and technology. We have also arranged things so that almost no one understands science and technology. This is a prescription for disaster. We might get away with it for a while, but sooner or later this combustible mixture of ignorance and power is going to blow up in our faces" (Sagan 1995).

Sagan frames the central problem that *should* motivate all secondary high school teachers, but unfortunately the motivation for both student and teacher in the modern science classroom has become increasingly based on performance on standardized tests and meeting state standards. That is to say, public schools are motivated by standardized test score data. The focus is placed on the *memorization* of science mostly in the form of unrelated facts, and not the *process* of science.

For example, the administration of Western School District (where this study was performed), has embraced a popular school management program called Professonal Learning Communities (or PLCs) (DuFour 2005). The impetus for this PLC movement is to place the focus on student learning rather than on what is being presented in the classroom. The idea is that you can improve student comprehension with a systematic cycle in place. A learning cycle is implemented under PLC where a lesson is presented, the students are assessed to determine what was learned, and then based on assessment data, students are remediated or moved ahead in a systematic way (ibid).

The problem with this approach is the assessment piece of the learning cycle. The PLC method is based on accepted research (eg. Bratt 2010) and what is currently accepted as educational best practice (eg. Bransford 2000). However, assuming a student has learned or not learned a scientific concept based on performance on a standardized test is not giving a full picture of the student's ability to *use* the science. DuFour's PLC program is just one example of school reform philosophies that have gained acceptance as educational best-practice in recent years.

Similarly, in the book Classroom Instruction That Works, Marzano et al. (2001) showed that traditional teaching techniques such as lecture and note taking result in student achievement according to their metrics. They point out that techniques such as having students identify similarities and differences between concepts and home work practice show an increase in student achievement between pre- and post-tests of 45% and 28% respectively.

While these findings are impressive and are no doubt a critical part of educational best-practice, the problem for the science teacher is the definition of "student achievement". Does that mean the student has memorized the definition of various scientific theories and terms? Does that count as an understanding of science? Does it mean the student could use the knowledge to design future experiments or solve future problems? The unique problem the high school science teacher faces that other secondary teachers do not grapple with (at least not in the same way) is the definition of student achievement. Increase in student learning (DuFour 2005) or a classroom policy that "Works" (Marzano 2001) are measuring efficacy based on tests that measure students' acquisition of knowledge. But science is more than acquisition of knowledge or memorization of factoids. It is a process and a way of thinking. Although Marzano is very thorough in presenting analysis of his findings, the definition of exactly what "student achievement" means is a little hazy. Classroom Instruction That Works defines student achievement based on performance on "Higher Level Questioning Strategies".

Marzano's (1998) research gives examples of these higher level questioning strategies. The assessment strategies Marzano uses to back up his research are indeed deeper probing questions and would take a level of sophistication and synthesis on the student's part in order to answer effectively. However, after reviewing these assessment strategies, a science teacher is still left feeling that the student has not "done science" after successfully addressing the assessment questions. Few researchers argue that acquisition of rote knowledge is not important in the science classroom (and consequently philosophies like DuFour's PLC program, or Marzano, Pickering, & Pollock's Classroom Instruction That Works should be a part of best-practice when teaching science), but research and opinion support that increased scores on assessments do not give a complete picture of student understanding in a high school science classroom. For example, Tchudi and Lafer (1996) describe traditional assessment as "a game that engages the student in guessing what the teacher wants rather than demonstrating the best they can do", and Pigliucci (2007) states that a science classroom that is expected to conform completely with traditional accepted educational paradigms (such as Marzano's or DuFour's);

> "conveys the message that science is as boring as reading the yellow pages (which it is, if one simply enumerates all the factoids that are contained in the typical textbook); second, it unfortunately reinforces the idea that science is all about results that are somehow – and without discussion of scientific methodology might as well be magically – generated by people who dress in white coats and engage in mysterious activities. Little appreciation for the process of science is developed, and with each generation, we are directly responsible for rearing and educating citizens who will have no idea, for example, why global warming might be a threat and, most importantly, how we know that it is (or is not)" (Pigliucci 2007).

Pigliucci's opinion reflects the lack of connectedness of classroom content to what students observe every day. This is very frustrating to the high school science teacher. Many teachers attempt to use hands-on activities and labs to show students that science is a process and not a memorization of facts.

Hands-on lab activities are a more engaging way of teaching science, but still do not encourage the students to think through scientific problems. Most often, the laboratory experience in a high school science classroom involves students following a written set of directions in order to arrive at a predestined conclusion. These types of hands-on activities are really just another method of delivering wrote-memorization of material. They may have value, but again, like Marzano's and DuFour's strategies, they fall short of having students experience the process of doing science. Pigliucci (2007) continues;

> "a shift in emphasis from traditional classroom lectures to "hands-on" activities in which students manipulate objects and perform experiments. Moving away from lectures and getting students to actually do things is an excellent idea, but the way the hands-on approach is often implemented, especially at the pre-college level, may actually produce worse results than the traditional lecture approach"

The hands-on laboratory exercises have a part in the science classroom, but they should be recognized for what they are: practice with research techniques, but not actually acquiring new information though observation and testing of hypotheses – not doing science.

Secondary students often express frustration, saying that both laboratory exercises and lecture material are reviews of already understood phenomenon. The combination of this with inadequate measures of student understanding leads to boredom in the classroom. Controversial writer, researcher, and New York Teacher of the Year John Taylor Gatto (2001) commented that in his 30+ years of classroom experience;

> "Boredom was everywhere in my world, and if you asked the kids, as I often did, why they felt so bored, they always gave the same answers: they said the work was stupid, that it made no sense, that they already knew it. They said they wanted to be doing something real, not just sitting around. They said teachers didn't seem to know much about their subjects and clearly weren't interested in learning more. And the kids were right: their teachers were every bit as bored as they were"

The good news is that science is naturally engaging to students... if they are allowed to do real science. The system of education has just tried to place constraints on the exploration of science. These constraints have grown out of good research and good reasoning. But the current secondary educational system neglects the fact that science is a process, not an acquisition of factoids.

The problem a science teacher then faces is: how can one teach using research-based best-practice (e.g., Bransford 2000) while still allowing students to see science as an engaging, systematic way to answer questions about the unknown phenomenon that surround the students (and are going on inside their own bodies) every day? My analysis of what has been described above leads to the following summary of the shortcomings of the current secondary high school classroom:

From the policy makers / curriculum developers perspective:

1. A logical system of traditional teaching techniques exists that is research based and produces results. It is difficult to argue that these traditional techniques should not be used.

2. The results (student performance) from these traditional techniques are quantifiable and easily assessable using standardized tests. This makes the traditional system attractive to school administrators and government policy makers that need to gage performance in order to make funding decisions. The simplicity of the traditional science classroom make policy and curriculum designers resistant to new means of engaging students in science.

From the learner/student perspective:

1. Under these traditional parameters, science becomes stagnant and boring for the student. The emphasis is taken away from creative problem solving and the focus is on memorization and performance on standardized tests.

2. The student entering the professional world does not understand the problem-solving aspect of science because secondary education places no emphasis on it.

3. As a society, we are at a critical moment in history where we need more students leaving high school interested in science and talented at problem solving. Traditional public school science classrooms are producing the opposite.

Rationale: Description of Problem Based Learning at the secondary level

Based on this information and my analysis, is there a solution to this multi-faceted problem that benefits the teacher, student, and policy makers? Can we keep students interested in science while still allowing them to perform adequately on standardized tests? And, perhaps most importantly, can we prepare students to do authentic science and acquire new skills on their own in our quickly changing economy?

It is expected an educational approach called Problem-based Learning (or PBL) may hold some of the answers. PBL is a "learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem" (Savery 2006). The focus is placed on the learner and the learner is expected to explore a complex problem.

Gallagher & Stepien (1993) hit many key points that make up a PBL.

> "Through Problem-Based Learning, students learn how to use an interactive process of assessing what they know, identifying what they need to know, gathering information, and collaborating on the evaluation of hypothesis in light of the data they have collected. Their teachers act as coaches and tutors: probing findings, hypotheses, and conclusions: sharing their thinking when students need a model: and attending to metacognitive growth by way of "time out" discussions and how thinking is progressing"

The general structure of a PBL technique can be summarized from work done by John Savery (2006), MacDonald (2004), and Margaret Waterman (1997). This step by step process (Table 1) formed the backbone for the PBL process used in this study.

Table 1: PBL Process

Step 1	Students are presented with an ill-structured problem
Step 2	Students collaborate and share previous knowledge of the topic. They may develop testable hypotheses at this stage, or may just brainstorm ideas to learn more about.
Step 3	Students determine what they already know, and what they need to find out in order to make a more educated hypothesis.
Step 4	Students research the unknown (research published information or experiment)
Step 5	Students bring newly acquired knowledge back to the collaborative group. The group identifies what is now known and refines the hypothesis.
Step 6	Students go back to step 3 and continue the process (which becomes cyclical at this point).

The teacher plays a complex role in the PBL cycle. They coach the collaborative interplay, direct the discussion towards the goals of the curriculum, and sometime offer expertise to speed the progress of the students (although this requires caution on the teachers part. PBL is ineffective if the process is not student directed). The teacher also needs to assess progress of all students and make adjustments accordingly.

The process ends with a well developed hypothesis regarding the initial problem. Unlike similar approaches such as case-studies or inquiry problems in a didactic classroom, the PBL conclusion does not end with a “solution” to the original problem, but rather a more refined and educated understanding of the parts that make up the theories and postulates (Savery 2006). The goal of the process is a refined and logic based hypothesis – possibly more than one hypothesis – developed by the students and their collaborative work.

Developing the PBL problem is challenging. This problem "must be ill-structured and allow free inquiry" (Savery 2006). The term "ill-structured" seems odd to one that is not familiar with PBL, but it means a good PBL problem should be inconclusive. It should be a problem that may have more than one explanation. It should also be an actual problem; one that has not been sufficiently explained completely by current scientific understanding (ibid).

How PBL addresses the shortcomings of the traditional classroom.

Unlike traditional teaching methods that segment secondary educational content into disciplines, PBL encourages the student to use information from multiple areas. Lee and Ward (2002) note that "few problems facing our society are aligned within disciplines" and their research goes on to find that Problem Based Learning at the secondary level produces students with critical thinking skills. The PBL student sees science as an interdisciplinary method of solving problems. This is a contrast to the traditional method commonly consisting of notes, lecture, textbook readings and reinforcement assignments that perpetuate the impression that science is a memorization of compartmentalized factoids (ibid).

PBL moves student learning in the secondary classroom away from rote memorization and towards critical thinking and problem solving skills, but a reality of the traditional school settings is student achievement measured by standardized tests. From a school administrators perspective, any educational tactic implemented in a classroom must produce favorable student performance on standardized tests. Some researchers suggest that PBL students may not perform as well on these traditional forms of assessment. Examples include Lee and Ward (2002) and more recently, Clark et al. (2006) in which the conclusion is reached that PBL produces no benefit to students. But in a direct response to Clark et al. (2006), Hmelo-Silver et al. (2007) states "evidence suggests that these approaches [PBL] can foster deep and meaningful learning as well as significant gains in student achievement on standardized tests." and goes on to site PBL studies at the secondary level that support her opinion and invalidate Clark's et al. (2006) findings. Still more research shows little difference in student performance on traditional tests between groups receiving PBL instruction and groups receiving traditional, lecture-based instruction. Examples at the post-secondary level include Albanese & Mitchell (1993). Even more relevant to this study, Burris (2005) also found very little difference in test scores between groups of secondary PBL-treatment students and secondary students receiving more traditional treatments. In a study comparing traditional and problem-based instruction in high school economics, Mergendoller, Maxwell, and Bellisimo (2006) found that across multiple teachers and schools, students in the PBL course gained more knowledge than the students in a traditional course.

Contrary to the findings of PBL's detractors (eg. Clark et al. 2006), PBL students do perform comparably, and in some cases even favorably, with non-PBL students. These findings are not surprising when one starts to compare PBL methodology to other popular educational paradigms such as DuFour's Professional Learning Communities or

Marzano's Classroom Strategies That Work because, like those philosophies, PBL is learner-centered and the learners will need to research and become fluent with basic scientific principals in order to solve a problem. This allows PBL to fit into a traditional curriculum framework, use some traditional methods, and still make progress towards the standardized test goals of administrators and government policy makers.

Another difference between PBL and the traditional didactic approach is the student perception of the content being presented. From the student perspective, PBL allows students to *do* science. Hmelo-Silver et al. (2007) and Burris (2005) both concluded that PBL students showed more interest in the material being covered likely due to the nature of student responsibility for the material covered. In an older Hmelo study (1994) she explains that the traditional didactic approach leads students to what she called "data based reasoning", while PBL produced students more fluent with "Hypothesis based reasoning". Data based reasoning is directional and memorization based. If "A" is true, than "B" is the conclusion. Hypothesis-driven reasoning, on the other hand, takes into account many factors and observations and then leads the student to explore these possibilities. A hypothesis-driven line of reasoning may look more like; A female cat has a tortoiseshell coat coloring pattern. This could possibly be because she is a chimera, or she is genetically abnormal due to an environmental influence, or different X chromosome genes are being expressed in different regions.

This increase in hypothesis-driven reasoning addresses the problems faced from the student perspective in a traditional classroom. The PBL group in the Hmelo (1994) study shows a fluid understanding of scientific problems, not a stagnate memorization of factoids. The hypothesis-driven knowledge is considered more flexible and useful in a changing world.

While Hmelo (1994) does not elaborate on student enthusiasm, it is hard to imagine that students in a PBL setting would not be more pleased and engaged in learning. This assumption is confirmed by several studies. For example, Savery and Duffy (1995) found that "learner motivation increases when responsibility for the solution to the problem and the process rests with the learner". Ward and Lee (2002) also found increased student enthusiasm based on student attendance comparisons between PBL and non-PBL classes. PBL groups showed attendance rates consistently over 80% and traditional classes covering the same material consistently at attendance levels below 80%. Student apathy is alleviated in a PBL setting because students are not memorizing science, they are approaching problems as a scientist would.

In addition to more flexible knowledge and more motivation to gain that knowledge, some research suggests that learners in a PBL environment benefit from unintended effects of the PBL method. For example, many state standards (including the Michigan High School Content Expectations) include inquiry skills as one of the benchmarks all students are expected to master. Students in a PBL environment would be very familiar with inquiry based skills. Inquiry involves students generating hypotheses and using observation and experimental design to test them. These inquiry skills are a necessary imbedded part of a PBL.

Another unintended bonus for students in a PBL classroom would be team working skills. Collaboration is a key part of the PBL process. In a traditional classroom, progress is made when an assignment is completed. In a PBL classroom, progress is made when a new idea is proposed and can then be researched, manipulated, and debated by the other members of the group. The PBL model of team work is more reflective of the workforce students are supposedly preparing for (Savery 2006).

Comparable (and perhaps superior) standardized test performance, critical thinking skills, more motivation, and team working skills are goals most secondary teachers strive for. The research mentioned above shows that a PBL unit has the potential to produce all of these outcomes at the secondary level. PBL has the capacity to solve the shortcomings that exist in the traditional secondary science classroom. The research suggests that PBL will be a win-win situation for public school science classrooms.

Adapting PBL to the High School Classroom

Problem-based learning is an attractive technique to use in a high school science classroom because it can appease many of the parties involved in secondary education. However, there are some complications in using PBL at the high school level. These need to be addressed when using PBL at the secondary level and will be a primary concern in the implementation of this study.

One large problem is motivating the high school student to engage in the process. "If teaching with PBL were as simple as presenting the learners with a "problem" and students could be relied upon to work consistently at a high level of cognitive self-monitoring and self-regulation, then many teachers would be taking early retirement" (Savery 2006). In a medical school or even undergraduate classroom, the student is typically highly motivated and invested in their education. This may not be the case with a high school student.

Historically, PBL was not developed with the high school classroom in mind. Problem-based learning was developed by several medical schools and colleges over the last several decades. It is described by Boud and Feletti (1997) as having:

> … "Evolved from innovative health sciences curricula introduced in North America over 30 years ago. Medical education, with its intensive pattern of basic science lectures followed by an equally exhaustive clinical teaching programme, was rapidly becoming an ineffective and inhumane way to prepare students, given the explosion in medical information and new technology and the rapidly changing demands of future practice." (Boud & Feletti 1997).

Like modern day high schools, medical schools were seeing that traditional techniques were preparing students for memorizing how to use current technology and not how to dynamically incorporate and use new technology and information as it became available. Because the PBL was developed for medical students, the target audience in much of the PBL literature is highly motivated, highly educated, mature students. The high school teacher is dealing with a different target audience that often lacks motivation.

Another complication may present itself because PBL also relies heavily on literature and experimental research. Because traditional educational techniques do not emphasize research and student synthesis of knowledge, it is expected that a high school student will need to be instructed how to do scholarly research. This will require some prerequisite instruction time. Fortunately, some difficulties concerning students' research skills may be alleviated due to progress in information technology. Now is the time to re-examine the feasibility of PBL in the high school classroom. Access to high speed internet is becoming more and more ubiquitous. We live in "interesting times- students can now access massive amounts of information that was unheard of a decade ago" (Savery 2006).

One worry is that with so much information at their disposal, and the limited research skills of high school students, it will be difficult to get students to focus on the major goals of the PBL unit without getting lost in miniscule details of the problem or wandering away from the focus problem entirely. An article in the Journal of Educational Leadership suggest using "post hole" problems as a way to course correct. A post hole problem is described as smaller questions that can be put into the collaborative problem solving effort by the instructor. These post hole problems serve to redirect the flow of information without putting the teacher back in the role of "information giver", ensuring that the PBL unit still focuses on student learning rather than the teacher supplying all of the information to araive at the conclusion.

A final major concern facing an educator wishing to implement PBL at the secondary level may be the constraints of the typical high school schedule and classroom. PBL requires time to do research, time to collaborate, and time to compile information. This is difficult to do in a fifty-four minute period and requires careful planning in the implementation of this study or with any effort to place a PBL curriculum in a traditional secondary setting.

Class size may also be a problem. Lohman and Finkelstein (2000) suggest that collaborative PBL groups larger than eight individuals show a dramatic drop in self-motivated learning. Their research also found that student reflections on the PBL experience was far more favorable when in small and medium sized collaborative groups. In a typical high school classroom approaching 30 (or more) students, group size will need to be a consideration.

Rationale for implementing PBL in a high school anatomy class as a way to teach bone and muscle physiology:

In order to ease some of the complications that can arise from implementing PBL at the secondary level, this study will use a class that has some parallels with medical school classes were the PBL concept was developed. Biological science lends itself to developing ill-structured problems, and a class with a focus on human Anatomy and Physiology will help make a compelling problem to frame student learning.

Also, it was given much consideration that the selected class for this study gave the teacher the flexibility to use extra class time and a more motivated segment of the student body. For these reasons, an elective Anatomy and Physiology class at Western High School in Parma, Michigan was selected for the site of this study. The curriculum for this class is flexible and set by the teacher. It covers all of human anatomy over the course of a full school year. There are no state content expectations to meet.

It is expected that the increased flexibility and time afforded by the structure of the Anatomy and Physiology class will make the adoption of a PBL approach go smoothly. It should also be noted that PBL takes some talent and adjustment on the teacher's part. As discussed earlier, the teacher's role changes from presenter of information to facilitator of learning. It is more of a coaching role than a teaching role and will no doubt take some adjustment (Waterman 1997 & Savery 2006). For this reason, a course the teacher was comfortable with and had taught for many years was selected so that knowledge of the material would not be an issue and the teacher could focus on developing his PBL facilitator skills.

Bone and muscle physiology was the specific unit chosen for this study for several reasons. First, it contains some of the most complex physiology covered in course. For example, students have a difficult time understanding the role of calcium ions as both a structural element in bone physiology and a chemical component of the muscle contraction process. Homeostasis of calcium ion concentration in the body is one continuous process involving bones and muscles, but students often have a difficult time making this connection because a traditional approach in an Anatomy and Physiology class often teaches the two systems (bones and muscle) as two separate chapters or units. A PBL approach to the same unit will break down these divisions and encourage students to gather information from sources other than the specific "unit" they are covering. By its nature, PBL approaches Anatomy and Physiology in a fundamentally different way than the traditional compartmentalized body systems presented in the chapters of a text book. The interconnected nature of the entire body can be emphasized by this approach.

Another reason bone and muscle physiology was the focus of this study was the attempt to address the issue of student motivation. As discussed earlier, PBL originated in medical schools and the target audience was highly-motivated medical students. PBL fosters more student interest, but also requires some level of interest to get the collaboration and research started. High school students may lack the drive and interest to explore the ill-structured problem with any depth and drive unless they see relevance to their lives. Since Western High School's Anatomy and Physiology class typically attracts a high percentage of student athletes (specifically many members of the cross-country team), it is expected that a unit on bone and muscle physiology may intrigue athletes who use, and consequently frequently injure, their bones and muscles.

Another reason the relationship between the skeletal and muscular systems is the focus of this study is because of the many fundamental physiological and biological concepts and ideas that the students may be exposed to during the course of the PBL unit. The fundamental factors include cellular respiration, cell growth and repair, hormone signaling, water chemistry, and osmosis & diffusion. An understanding of these concepts will carry over to the other body systems that will be covered throughout the remainder of the year.

Lastly, bone and muscle anatomy and physiology was chosen because some aspects of these systems are still mysteries to the scientific community. The basic anatomy and physiology of bones and muscles is well documented and fairly simple, but injuries and homeostatic mechanisms of bones and muscle may involve cell signaling, transduction pathways, transcription factors, cell cycle control, and cellular nutrient and waste management that are still somewhat mysterious in medical science (eg. McCabe 2007). Basing a PBL unit on truly as-of-yet unknown or unclear phenomenon is key to making a good PBL ill-structured problem. One of the cornerstones of the PBL method is that students are able to do actual research on topics that are of current interest to the scientific community.

The science and the goals of the unit

At the end of the PBL skeletal and muscle anatomy and physiology unit, students should be able to describe that bones are made of a matrix composed of living cells, protein filaments, and calcium carbonate. These bones are not static and change in response to stress placed on them. This change in bone physiology is due to active cells living in the osteon of all bones known as osteoblasts and osteoclasts. These cells are responsible for laying down new bone matrix in areas receving more stress and breaking down bone matrix (releasing Ca^{2+} ions into the blood) in areas of low stress respectively. The action of the osteoblasts results in new bone tissue that form an organized structure known as an osteon that makes up the basic physiology of all bones. Students should also know that on the macroscopic scale, long bones have distinctive regions with varying densities and different functions. The epiphysis of the bones are made of low density spongy bone that serves as a fat storage tissue as well as being a large surface facilitating articulation of joints. The diaphysis of bones are made of dense compact bone and contain a cavity filled with bone marrow where blood stem cells are produced.

At the end of this unit, students should also be able to identify the different types of muscle present in the human body, with an emphasis on the skeletal muscle that pulls on the skeletal levers (bones). Students will need to know that the muscle tissue is made of bundled bundles of muscle fibers (cells) that are held together with connective proteins of the extra-cellular matrix. These connective tissues are continuous with the tendon at the ends of skeletal muscle units, which are continuous with the periosteum that surrounds bones. Students should know that an electrical impulse from the nervous system triggers the release of a neurotransmitter at the neuro-muscular junction which diffuses into the t-tubule of the muscle fiber. The t-tubule allows diffusion of the neurotransmitter to the calcium ion pumps of the sarcoplasmic reticulum. Calcium ions diffuse from the sarcoplasmic reticulum into the sarcoplasm where it causes a configuration change between tropomyosin and actin fibers allowing myosin to ratchet up the actin filaments pulling z-lines together. This results in muscle fiber contraction and movement of the body. Energy for the ratchet mechanism (as well as for active transport of Ca^{2+} ions and other cell functions) is supplied by ATP produced during cellular respiration.

This is the minimum amount of material students will be expected to know upon the conclusion of the PBL unit. It is expected that most students will go above and beyond the basic nuts and bolts of how these two systems work and interact. It is the job of the teacher to make sure these basics are covered within the parameters of the PBL unit and that students do not spend too much time and effort exploring non-essential parts of bone and muscle physiology.

The hypothesis of this study is that PBL can be successfully implemented in a high school classroom, leading to an increase in student understanding that can be measured with traditional forms of assessment. Use of PBL will reflect other benefits to student learning (such as critical thinking and team-working skills discussed above) that are less tangible than test scores.

Relating rational to research work on-campus.

Research at Michigan State University during the Summer of 2009 included investigation of possible solutions to frustrations experienced in the traditional science classroom. Once it was established the PBL may be an effective method of modifying the traditional techniques to alleviate student and teacher frustration, much time was spent learning how to construct an effective PBL unit.

Expert advice on how to effectively administer a PBL unit was sought from members of the Michigan State University faculty. I met with Jan Eberhardt and Dr. McCabe. Their expertise dealing with PBL and Anatomy and Physiology respectively, showed methods and pitfalls to be aware of in order to successfully implement the PBL unit.

Time was also spent in the Summer of 2009 developing the goals of the unit, the PBL ill-constructed problems to guide the unit, and hands on activities that allowed students to do more than base all of their research on published articles. It was important to have activities that allowed students to explore their own questions and gather and analyze data that they produced.

Exploring efficacy of traditional methods such as lecture, note taking, and popular recent educational philosophies and comparing those methods with PBL methods made up the remainder of the time spent researching this study.

Research Setting

Parma/Spring Arbor MI and Western School District

Parma and Spring Arbor are small, neighboring towns in Mid-Michigan on the west side of Jackson County. At the time of the 2000 census, 907 people lived within the town of Parma with 8% of people having attainment of a Bachelor of Arts or higher, per capita income of $16,483, and a poverty status of 1.8%. Median home value in Parma was $85,500 (census.gov). The town of Parma is a farming community that is experiencing financial distress as family farming becomes a less viable source of income. At the time of the 2000 census, 3110 people lived within the town of Spring Arbor with 24% of people having attainment of a Bachelor of Arts or higher, per capita income of $21,587, and a poverty status of 9.2%. Median home value in Spring Arbor was $120,200 (census.gov). Spring Arbor is home to a small liberal arts college (Spring Arbor University). Western School District serves these two communities providing K-12 education. There are three elementary schools, one middle school, and one traditional high school and one alternative high school. Today the district provides educational services for nearly 2800 students, employs approximately 325 people within the district, and is supported by an annual budget of approximately $23,000,000. Western High School houses grades 9-12 and has a student body of approximately 900 students (Western School District 2010).

This study was conducted in an Anatomy and Physiology class at Western High School. This class is offered to eleventh and twelfth grade students who attained a grade of 87% or higher in 10th grade Biology and have taken or are concurrently taking Chemistry. 24 students participated in the study. 19 students were female and 5 were male. Grade point averages ranged from 2.3 to 4.0 for these students (Western School District 2010).

Implementation

This study was implemented in the fall of the 2009-2010 school year. Before implementation of the bones and muscles PBL unit, students had experienced two units taught using traditional methods including lecture, note taking, textbook reading assignments, and reinforcement homework assignments. These units included an introduction to human anatomy and physiology and anatomical terminology, and a short review of cellular biology. It was important that students have experience with traditional methods leading into the PBL unit so comparisons could be made by students when answering survey questions.

Immediately preceding implementation of the PBL unit, students required instruction on how to do library and internet research by the school's librarian. She helped students with researching internet academic journal articles and showed students how to use resources for accessing primary research sources through the high school library. This mini-unit took three days.

The Muscle, Bones, and Neuromuscular Junction PBL Unit

All students ($n = 24$) in the Anatomy and Physiology class participated in the study. Students were put into three collaborative groups of eight students each. Effort was made to evenly distribute males and females, student athletes, and grade point averages within these collaborative groups in order to end up with heterogeneous groups. The largest groups that would still allow effective PBL (8 students according to Lohman and Finkelstein, 2000) were used in order to cut down on the number of groups the instructor would need to meet with in a class period.

The unit was split into three sections. Each section began with a pre-test, and concluded with a post-test. Within each section, there were two PBL problems for a total of six PBL discussions. Each discussion began with "4-W time". This process involved the class reading the problem all together, then they would collaborate in their groups of 8 students, and then they listed as a class on a large white board:

1. What is the problem(s) we are trying to solve?
2. What information is in the problem?
3. What do we bring as prior knowledge?
4. What do we need to find out?

At the conclusion of 4-W time, the students decided what groups would research which topics, and within the groups, each individual would then be assigned specific parts of the topic to research and bring back to the group the next day. The following day, students brought their research back to their group, the group would confer, compare, and debate their findings and sources, and then add their information to the original list on the white board. The day after 4-w time generally involved a lot of discussion and generated new questions. A second research and discussion day was included for a total of three class days and two nights of research completed for each question.

Within each of the three problems was one hands-on activity. These activities were designed to supplement the PBL unit and were implemented at different times depending on the goal of the activity. The muscle lab was implemented at the end of the muscle PBL as a summary of what the students were expected to learn, the bone lab was used as an introduction to basic bone anatomy and physiology and was implemented at the beginning of the bone section, and the neuromuscular junction lab was used as a part of the 4-W research and occurred in the middle of the research and discussion of Problem #3.

Once the problem had been sufficiently explored, students were required to write a summary of each two-part problem. Table 2 outlines the specific sequence used to implement this new unit:

Table 2: Implementation Timeline

Time	Activity in Class
Day 1 and 2	•What is PBL Lecture •Pre-Test Muscles
Day 3	•Problem #1 Part a: 4-W time
Day 4 and 5	•Students report what they found out to their group •Students generate new questions about Problem #1 Part a
Day 6	•Students summarize their findings reguarding Problem #1 Part a •Begin Muscle Contraction Lab in order to experience their findings
Day 7	•Finish Muscle Contraction Lab
Day 8	•Problem #1 Part b: 4-W time
Day 9	•Students report what they found out to their group •Students generate new questions about Problem #1 Part b

Table 2 Continued

Day 10	•Students summarize their findings reguarding Problem #1 Part b •Assign summary writing assignment for Problem #1
Day 11	•Recap and summarize group findings in preperation for muscle section test
Day 12	•Post-Test muscles
Day 13 and 14	•Pre-Test Bones •Problem #2 part a: 4-w time
Day 15 and 16	•Bone lab and discuss what it means to Problem #2 part a
Day 17 and 18	•Students report what they found out reguarding Problem #2 part a •Students generate new questions about Problem #2 part a
Day 19	•Students summarize their findings reguarding Problem #2 part a •Problem #2 part b 4-w time
Day 20	•Continue Problem #2 part b 4-w time
Day 21	•Students report what they found out reguarding Problem #2 part b •Students generate new questions about Problem #2 part b
Day 22	•Students summarize their findings reguarding Problem #2 part b •Assign summary writing assignment for Problem #2
Day 23	•Recap and summarize group findings in preperation for bone section test

Table 2 Continued

Day 24	•Post-Test Bone
Day 25	•Pre-Test Neuromuscular Juction •Problem #3 part a: 4-w time
Day 26	•Students report what they found out to their group •Students generate new questions about Problem #3 Part a
Day 27	•Students summarize their findings reguarding Problem #3 part a •Problem #3 part b 4-w time
Day 28	•Continue problem #3 part b 4-w time •Begin Neuromuscular Junction Lab •Assign summary writing assignment for Problem #3
Day 29	•Finish Neuromuscular Junction Lab •Students report what they found out to their group
Day 30	•Recap and summarize group findings in preperation for neromuscular junction section test
Day 31	•Post-test Neuromuscular Junction

Assessments

As indicated in the implementation timeline, the PBL unit was split into three different problems. (See Appendices II-A through II-F). Within each of the three PBL problems, student comprehension was assessed in three different ways. These assessment techniques will be used as the measure of the effectiveness of the PBL unit.

1. Student PBL discussion and in-class participation

Students were assessed based on what they brought to the discussion. This was not a formal graded assignment, but during the discussion and collaboration time, students were asked to participate and add ideas to the board. The teacher / facilitator involved students in the discussion by calling on them. Because each of the groups was working on separate parts of the overall problem, there was plenty of information for each individual to contribute. The teacher / facilitator made suggestions as to how to gather more and better information based on strength and relevance of what students were bringing to the discussion. In this manner, the in-class discussion acted as a fluid process of assessment and immediate feedback. A rubric was implemented in an attempt to quantify student discourse and participation. The rubric was filled out by the teacher in his notes as he facilitated and guided the discussions. For each of the six PBL problems, the 4-W time was evaluated using the following rubric:

1 = Students were disinterested. The teacher needed to call on individuals to facilitate any sort of discussion.

2 = Students were somewhat interested in researching and discussing the topic. The teacher needed to call on some individuals to get them to speak or step in to quiet some individuals so all students may have a chance to speak.

3 = Students were very engaged and motivated to speak. The teacher played a small role in the student-directed discussion and collaboration.

2. Tests and quizzes: Appendices III-A through III-F

The second form of assessment was formal tests and quizzes (Appendices III-A through III-F). Both pre-test and post-test versions of these questions were given at the beginning and end of each problem-framed section of the PBL unit.

Because part of this project was to gauge students' performance on traditional form of testing when using a PBL process, these quizzes were crafted to assess student's comprehension of factoids. The tests and quizzes attempted to reflect the kinds of questions that might be seen on a standardized test. Many of the questions were the same or similar to questions that have been used in this class in years past, where traditional, non-PBL methods were used to deliver the information. The hypothesis is that PBL will yield the same or similar outcomes to traditional methods on standard forms of assessment.

The pre-tests for all three sections (muscular system, skeletal system, and neuromuscular junction) were multiple choice tests. The first two sections had ten multiple choice questions each. The neuromuscular junction section pre-test consisted of five multiple choice questions. The post-tests consisted of identical multiple choice questions to the pre-test and also included additional questions and short answer responses. Students gain in comprehension was measured by comparing pre and post PBL unit scores. Multiple choice questions were assigning a pass / fail (1 /0) grade for each item. The essay responses in the post tests were graded using the following rubric:

0 = Student did not attempt to answer or shows absolutely no knowledge of the topic.

1 = Student used some appropriate vocabulary, but failed to make logical connections and showed very little understanding of the subject.

2 = Student had a partially correct or logical answer, but still maintained some misconceptions.

3 = Student answered correctly, but more support or information could have been given to show complete understanding of the topic.

4 = Student answered correctly and completely supported their reasoning.

3. *Hands-On Laboratory Explorations: Appendices IV-A through IV-D*

The third form of assessment was homework questions the students were to complete using information they gathered during laboratory exploration activities. Questions associated with the lab activities were designed to assess higher order thinking. These assessments aim at a student's hypothesis-based thinking skills. These questions are included in the Lab packets (Appendices IV-A through IV-C).

The three laboratory activities were revised and designed to be inquiry-based allowing students to discover information pertaining to their PBL problem. It was expected that these activities would supplement student research and lead to a deeper understanding of the PBL problem the students were working through.

Laboratory A: Controlled Muscle Fatigue: Appendix IV – A

Laboratory 1 (Appendix IV – A) was an adaptation of a traditional muscle contraction lab. In this exercise, students fatigued small muscle groups and analyzed what happed to on over-worked muscle group in terms of ability to repeat the contraction repeatedly. The major foci of this lab included:

#1: Students were to generate a hypothesis concerning trends they observed in their data. It was expected this experience would help students better understand what factors play a part in muscle fatigue and aid them in forming a hypothesis concerning their part-one PBL problem.

#2: Students were expected to understand what a controlled experiment means. By using an elaborate "muscle isolation box" and two-fingered glove, students movements were restricted and only the focus muscle group were fatigued. In previous years, a less controlled lab procedure was used. Students used just a clothes pin and opened and closed the pin repeatedly. When the students would experience fatigue, they would change the position of their arm or finger position, or use more fingers to overcome the uncomfortable feeling associated with muscle fatigue. This would change the results and no useful data were obtained.

By constructing an isolation box and glove (see Apendix IV – B), only two small muscles in the palm and forearm were used. Western High School's shop class helped construct 12 muscle isolation boxes so that teams of two students could perform the lab.

Laboratory B: Bone Anatomy and Density: Appendix IV – C

The bone anatomy and density lab was a new activity developed for this unit. The focus of this lab is to have students generate an understanding of a long bone's general anatomy. Students helped with the preparation of the bone sample. The most challenging part of this activity was obtaining a long bone. They can be purchased from biological supply catalogs, but for the size we were after, they were prohibitively expensive. We considered using a cat forelimb (this Anatomy class concludes the year with a cat dissection), but we did not want to open a dissection specimen, and the cat bones would have been too small to produce useful data.

Time was running out and we considered not doing the activity, but then a student killed a deer during bow hunting season and brought a forelimb in for the class to use. We stripped the limb down to the bone and prepared the Humorous, Radius, and Ulna for use in the laboratory activity. The size of the bones was perfect and produced fine results.

The activity involved analyzing the entire bone and identifying different parts by comparing it to diagrams from their book. The students drew and numbered sections along the length of the bone and cut the bone into pieces. Each piece of the bone was analyzed paying attention to how the anatomy differed in different segments of the bone.

Finally, the students measured volume of each bone segment using a displacement method and measured mass of each segment on a triple beam balance. From this information, density of each segment could be calculated. The anatomy and density information could then be used in concert with their research to develop a hypothesis regarding their part #2 PBL problems (appendix II C and D).

Laboratory C: Reaction time and physical activity: Appendix IV - C

This exercise was designed and executed by the students. For the collaborative part of the third PBL problem (appendix II-E and II-F), the students were presented with reaction timing equipment and they designed an experiment dealing with muscle fatigue and reaction timing. The focus of this activity was to get students to work like research scientists. They were given no directions other than the instructions on how to use the reaction timing equipment and a prompt that they developed from the class discussion.

As a class, they decided to have three different groups do varying levels of physical activity and then tested their reaction times. The resulting activity was student generated and yielded real information that further contributed to the PBL discussion.

4. *Written Assignment Responses: Appendix V – A through C*

Upon the conclusion of each PBL problem, students were to write a response concerning what they had learned from the experience.

5. Survey: Appendix VI

Upon completion of the entire PBL unit, students were asked a series of survey questions in order to document their thoughts and feelings concerning the PBL technique. The survey consisted of ten questions related to the hypothesis of this study and students feelings about the PBL unit. The survey used a 5 point Likert scale to measure student opinions.

Results / Evaluation

PBL discussion / student generated PBL ideas

The student performance in their discussions was above and beyond what was expected. The general reaction of the students was overwhelmingly positive. While these observations are completely subjective, the students' enthusiasm for the format was undeniable. During the first 4-W time, students were a little reluctant to discuss the problem for the first few minutes. But once discussion got started, the problem became using up class time too quickly. The students wanted more time to discuss and sort out ideas and information. Students that had not participated in any sort of class discussion up to this point in the year began to offer information and take part in the collaboration without the need for teacher prompting.

As discussed in the implementation section, a rubric was developed for assessing the effectiveness of the 4-W time. However, I found my rubric to be inadequate because of the overwhelming success of this format. 1's and 2's would indicate some reluctance to participate and teacher intervention would be required to prompt discussion. I expected to have at least some 1's and 2's. But what I found was that as students got more comfortable with doing research and anticipating how the discussion would progress, they became more and more tenacious about digging for information and coming up with more obscure bits of information to add to the discussion.

As a result of the student's enthusiasm for the PBL 4-W format, the rubric for this form of assessment came up with 3's across the board. A more specific rubric would have given more meaningful results, But the straight 3 ranking for all six problem sets does

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does show that the problem, discussion, and student synthesis of information resulted in a lively discussion with high student participation in all six problem discussions. Examples of exchanges during the discussions included a rather long and interesting debate about the importance of magnesium in muscle contraction. Student 3 considered the role of magnesium ions the most crucial factor in muscle contraction during the discussion of Problem #1 part b (Appendix II-B). She engaged in a debate with several other students in the class and used her research to support her case. This debate continued for nearly a half hour and touched on nearly every molecule necessary for muscle contraction. In the end, student 3 conceded that, although she believed (correctly) that magnesium ions are necessary for normal muscle contractions, it was not likely that a magnesium deficiency was the culprit of our PBL Problem. Other similar exchanges ensued over the role water plays in physiology (initiated by student 1), the importance of protein in compact bone structure (initiated by student 9), and whether or not sugar was a diuretic or an electrolyte… or both… or neither (nearly all students had an opinion with some sort of research to support their view). It was discovered that the most information-dense discussions usually involved one student feeling ownership of their piece of information they were contributing to the discussion and other students showing why that piece was insignificant or less significant to the PBL problem.

Traditional Assessment Pre and Post Tests and Quizzes

Item Analysis

Muscular System Pre-test and Post-test multiple choice assessment: Appendix III-A and III-B

Students' gains in performance from pre-test to post-test were impressive. Students showed a gain in performance on all test items. Table 3 shows the multiple-choice questions and average student scores on each test item. The data in table 3 were analyzed comparing the pre-unit and post-unit averages via a paired t-test analysis (two tailed, df=23) for each item. The t-test showed significant differences in student responses after completion of the unit, indicated by p-values less than 0.05. The only question that did not show a significant change in student understanding was question 8 (p-value 0.103), which shows that students missed some information pertaining to the basic physics of skeletal levers. This makes sense because no one had brought up skeletal levers yet in the PBL discussion time. In past years, multiplication of muscle contraction distance would have been discussed by this point, but the student-led PBL unit had not made it to this topic yet. Performance on question 8 shows one limitation to the PBL format; the pace of the class is controlled by the student led discussion, making timing of assessment during the unit difficult.

Table 3: Muscular System Pre-test and Post-test Item Analysis (*n* = 24)

Questions	Pre-test (appendix II-C) Mean Average number of correct answers	Post-test (appendix II-D) Mean Average number of correct answers	Percent Gain (pre-test average – post test average)	p-value
1. What is ATP?	62.50%	91.67%	29.17%	0.005324572

Table 3 Continued

2. What is glucose?	54.17%	95.83%	41.66%	0.000492867
3. What process is your body using to make ATP molecules from glucose right now as you sit?	16.67%	83.33%	66.66%	6.82404E-06
4. What is a neurotransmitter?	0.00%	79.17%	79.17%	2.6813E-09
5. Which is an example of an organ that is made of smooth muscle?	8.33%	91.67%	83.34%	2.01277E-10
6. What is fascia?	12.50%	70.83%	58.33%	6.02561E-05
7. Bones give skeletal muscles:	0.00%	95.83%	95.83%	2.25122E-17
8. Your skeletal "levers"	4.17%	20.83%	16.66%	0.103462046
9. What are the two kinds of myofibrils?	45.83%	100.00%	54.17%	2.75028E-05
10. All of these chemicals are necessary to muscle contraction besides:	0.00%	62.50%	62.50%	2.56964E-06

Skeletal Pre-test and Post-test multiple choice assessment: Appendix III-C and III-D

Table 4 shows the multiple-choice questions and average student scores on each test item. The data in Table 4 were analyzed comparing the pre-unit and post-unit averages via a paired t-test analysis (two tailed, df=23) for each item.

Question 8 showed insignificant gain in student comprehension (p-value =.77). Again, this is due to the structure of the PBL format. Because students had already researched, discussed, and dissected the muscle PBL problem, they had already had discussion regarding tendons. Because of this most students arrived at the bone section of the unit already knowing what tendons were. There was not much room for improvement.

Table 4: Skeletal System Pre-test and Post-test Item Analysis (n = 24)

Questions	Pre-test (appendix II-C) Mean Average number of correct answers	Post-test (appendix II-D) Mean Average number of correct answers	Percent Gain (pre-test average – post test average)	p-value
1. What are the epiphyses of a bone?	54.17%	91.67%	37.50%	0.001138944
2. What is a joint?	83.33%	100.00%	16.67%	0.042765957
3. What is the diaphysis?	50.00%	91.67%	41.67%	0.000492867
4. What is the Bone Marrow?	70.83%	100.00%	29.17%	0.005324572
5. Why do we have spongy bone?	0.00%	75.00%	75.00%	2.23621E-08
6. What does an osteoblast do?	29.17%	79.17%	50.00%	7.74499E-05
7. What parts of the bone contain living cells?	20.83%	95.83%	75.00%	2.23621E-08
8. What does a tendon do?	70.83%	75.00%	4.17%	0.770094577
9. How does the body respond to a bone fracture?	50.00%	100.00%	50.00%	7.74499E-05
10. Which of the following is true of bone anatomy?	25.00%	83.33%	58.33%	6.02561E-05

Neuromuscular Junction Pre-test and Post-test multiple choice assessment: Appendix III-E and III-F

Table 5 shows the multiple-choice questions and average student scores on each test item for this topic. The data in table 5 were analyzed comparing the pre-unit and post-unit averages via a paired t-test analysis (two tailed, df=23) for each item. Table 5 only shows significant gains in student comprehension (p-values less than 0.05) for question 3. Again, the data are consistent with the PBL process that had played out in the class over the month preceding this test. Much of the material on the pre-test had been covered in the student-led research and discussion before they took the pre-test. Because the nature of PBL is student driven, the instructor has little control over when information is acquired.

The only question that showed significant gain was concerning the role of water in neuromuscular function. Again, this is consistent with the PBL discussion that had happened in class. Students spent most of the time discussing the role water played in the last two PBL problems directly preceding the post-test.

Table 5: Neuromuscular Junction Pre-test and Post-test Item Analysis (n = 24)

Questions	Pre-test (appendix II-C) Mean Average number of correct answers	Post-test (appendix II-D) Mean Average number of correct answers	Percent Gain (pre-test average – post test average)	p-value
1. A neuron is also known as:	91.67%	100.00%	8.33%	0.161668056

Table 5 Continued

2. A neurotransmitter is:	95.83%	100.00%	4.17%	0.327715806
3. Water plays an important part in biology because:	25.00%	79.17%	54.17%	2.75028E-05
4. Tissues throughout the body respond to ________ signals	91.67%	95.83%	4.16%	0.574763999
5. How fast do signals travel from your brain to your leg muscles?	87.50%	95.83%	8.33%	0.327715806

Student Scores

Student test scores for the three PBL section multiple choice tests are shown in appendix I-A through I-C. Percent gain for each multiple-choice test is shown in Table 6. The scores show all students performing better pre-test to post-test. The class average percent gains show the most gain pre-test to post test during the Muscle section (58.8%), less gain pre-test to post-test during the Bone section (43.3%), and least gain pre-test to post-test during the neuromuscular junction section (15.8%). At first glance, these data seem to indicate student comprehension decreasing during the progression of the unit, but in reality, the pre-test scores increasing account for the decreasing gain in pre-test to post-test differences (See Appendices I-A through I-C). This shows that the PBL process is allowing students to make connections across different topics. For example, during the muscle discussion, students learned about tendons and calcium ion storage in bones, resulting in more prior knowledge being brought to the bone pre-test. Similarly, the muscle and bone discussions had already included many of the topics on the neuromuscular junction pre-test resulting in higher scores there.

Table 6: Percent Gain (Differences in Student Scores)

Pre-Test to Post-Test

Student	Difference (Post test – Pre test) Muscular Test	Difference (Post test – Pre test) Skeletal Test	Difference (Post test – Pre test) Neuromuscular Junction Test
S1	40	20	0
S2	50	30	40
S3	60	40	20
S4	70	50	20
S5	50	50	40
S6	70	60	0
S7	50	50	0
S8	70	30	20
S9	60	30	20
S10	60	50	0
S11	70	40	20
S12	80	50	20
S13	80	50	20
S14	60	50	20
S15	40	50	20
S16	30	60	20
S17	50	50	20
S18	50	20	0
S19	60	50	0
S20	50	10	40
S21	70	40	20
S22	60	60	0
S23	60	50	20
S24	70	50	0
Class average	58.8	43.3	15.8

Pos- test written responses

Written responses on post-tests also showed a generally high level of comprehension. A common problem in Anatomy and Physiology is breaking down the divisions between systems and getting students to see the human body as one system. The long answer responses showed thinking that demonstrated this. The PBL method allows students to make connections between seemingly unrelated systems and problems. For example, in a response to question 21 on the muscular test student 7 said, "Botox could also screw up your bones because once your muscles are paralyzed, they won't use calcium from your bones anymore". While her conclusion is incorrect, the statement shows logical reasoning across topics that would be compartmentalized in a non-PBL setting. In response to question 22 on the muscular system test, student 17 gave a detailed description of ATP synthesis including the statement "glycogen is produced in the liver and can be quickly changed into glucose, which is a molecule that contains energy to make ATP". In the past, this anatomy class did not cover glycogen or the liver's role in cellular respiration. The PBL unit did not limit students to information presented by the teacher. Several students had interesting responses to question 37 on the skeletal system test. Eight of the 24 students responded that osteoblasts and osteoclasts controlled calcium ion concentration in the blood in addition to sculpting bone. Student 22 said "Osteoclasts are responsible for adding calcium to the blood. Calcium is used by many different organs and the homeostasis of calcium needs to be controlled".

Muscular System Post-test Written Response Assessment: Appendix III-B

Table 7: Muscular System Written Test Section Student Scores

5-point rubric

Student	Question 19	Question 20	Question 21	Question 22
S1	4	4	4	4
S2	3	3	2	3
S3	3	4	4	3
S4	3	4	4	3
S5	3	4	4	3
S6	3	4	4	4
S7	3	4	4	4
S8	3	3	4	3
S9	4	4	4	3
S10	3	2	3	3
S11	3	4	4	4
S12	4	4	4	4
S13	4	4	4	4
S14	3	3	4	4
S15	3	4	4	4
S16	3	4	4	4
S17	1	3	2	3
S18	3	3	4	4
S19	3	4	4	4
S20	3	4	4	4
S21	3	4	4	4
S22	3	3	4	4
S23	3	4	4	4
S24	3	4	4	4
Class average	3.1	3.7	3.8	3.7

Skeletal System Post-test Written Response Assessment: Appendix III-D

Table 8: Skeletal System Written Test Section Student Scores

5-point rubric

Student	Question 36	Question 37	Question 38	Question 39
S1	4	4	4	4
S2	1	2	2	3
S3	4	4	4	3
S4	4	4	3	3
S5	4	4	4	3
S6	4	4	4	3
S7	4	4	4	3
S8	4	3	4	4
S9	4	4	4	4
S10	4	4	3	4
S11	4	4	3	3
S12	4	4	4	4
S13	4	4	4	3
S14	4	4	4	3
S15	4	4	4	3
S16	4	4	4	4
S17	1	3	4	2
S18	4	4	4	3
S19	4	4	2	4
S20	4	4	4	4
S21	4	4	4	3
S22	4	4	4	3
S23	4	4	4	3
S24	4	4	4	3
Class average	3.8	3.8	3.7	3.3

Laboratory Activity Question Responses and Activity Outcomes

Laboratory A: Controlled Muscle Fatigue: Appendix IV – A and B

This adaptation of a previously existing lab was quite successful. In the past, data generated from this lab led to confusion for students. The addition of muscle control apparatus had a dramatic effect on student data. Most groups (with the exception of the group consisting of S17 and S2) had data that showed a slight increase in number of repetitions in the first three trials as the muscle groups warmed up, and then a drop off in number of repetitions as the muscle groups fatigued.

These consistent data led to relevant conclusions that helped student's better understand the PBL problem being studied. When answering the short answer problems associated with the lab, many students showed deep understanding of the process that had been discussed in class during the PBL collaboration and were able to apply this information to a hands-on situation. Some quotations from student work follow that demonstrate this hypothesis-based thinking:

Student 4: "In order to become the clothespin squishing champion, I could train. Using the muscle a lot will make the muscle tissue better as storing glycogen which will allow faster production of ATP for the muscle".

Student 16: "Isolating the muscles makes it so you cannot use synergist muscles. Even small changes in position can make it so you start using different muscles besides the prime mover and they take over more and more of the work. This would make your data go up and down as you used different muscle groups".

Student 1: "I doubt water had much to do with my results, but if I were training to become the world's clothespin squishing champion, I would pay attention to how much water I drink. Water plays a part in calcium ion concentration as well as rates of diffusion of neurotransmitters. Water is critical to how nerve cells function and managing heat energy. For all of those reasons, water intake would be important to becoming the world's clothespin squishing champion".

Laboratory B: Bone Anatomy and Density: Appendix IV – C

The results of this lab were somewhat disappointing from the prospective of set-up work compared to what the students got out of it. Not that the students didn't enjoy it or gain some insight from it, but the work that went into setup was intense. Most students agreed that isolating the bones from the surrounding tissue and then sectioning the bone took most of the time (four class periods) and left a lot of down time for many students.

Once the bones were sectioned and density readings were taken, not much variation was observed in density from one end of the bone to the other. It was expected that the compact bone would have a noticeable density difference from the spongy bone regions. Unfortunately, the density was found to be fairly uniform across the sections of the bone (most samples were slightly above 1g/cc). The preparation of the bones involved a bleach treatment and many hours of boiling to remove tissue from the specimens. The students concluded that this treatment likely removed most of the proteins and fats from the bones, leaving mostly calcium carbonate behind. So density readings were fairly uniform because fat tissue (which would make up the majority of the variation in bone density) was no longer present in their samples. The lack of density information ended up being a learning opportunity for the students and caused them to develop various hypotheses as to why their findings differed from the information they had generated during our PBL collaborative time. For example, student 9 stated "proteins and fats are not stable in bleach and under boiling conditions, so it makes sense that our densities are all the same [between groups with different bone sample regions] because we are all measuring the density of the same substance".

Even though the density readings did not turn out, the students still got a hands-on look at bone anatomy. Student writings showed analytical thinking linked to the PBL discussion on bones. Student 20, for example, pondered "Under the stereoscope I see a rough surface that surrounds the marrow cavity. I'm not sure why the marrow cavity would not be smooth like I was expecting, but I wonder if it has to do with ostoclasts and osteoblasts reshaping the bone responding to stress inside the bone".

Laboratory C: Reaction time and physical activity: Appendix IV - D

The students generated an activity that explored the relationship (if any) between physical activity and reaction time. During discussion of PBL problem #3 part b (Appendix II-F), students hypothesized that high levels of physical exertion would decrease reaction time. The runner in the PBL problem experienced neurological problems of some sort and the students already knew that exercise uses up energy stores, water, and ions from their findings in previous sections. They hypothesized that exercise would also impair neurological function and result in slower reaction time. To explore this hypothesis the students designed a lab activity.

They divided the class into three test groups. One group of 8 students ran the trails behind the school for twenty minutes, one group walked at a slow pace around the track for twenty minutes, and one group rested at their desk for 20 minutes. At the end of the 20 minute period of activity, reaction times were measured using electronic reaction time devices.

The results showed that the high-level-activity group (the runners) had slightly better reaction times than the resting group. The resting and walking group had essentially identical reaction times. From this study's perspective, the lab showed some of the less tangible benefits of the PBL format. First of all, students had to agree on what the lab protocol would be. This took surprisingly little time. Within 15 minutes, students developed a procedure and split themselves into groups first by volunteers and then by drawing straws to end up with three equally divided groups.

This group effort highlights the collaboration encouraged by PBL. Traditional classroom techniques would not have fostered this kind of interaction. In the journal write following the activity several students made comments like "I didn't want to be in the walking group. I wanted to rest. But drawing straws was the only fair way to do it". (Student 21)

Another benefit of PBL highlighted by this activity was the rejection of a student-formed hypothesis. They had predicted that the high-activity group would have slower reaction times than both the rest and walking group. The results showed the opposite (although the data were only different by hundredths of a seconds). The students had to reject their original hypothesis. Student #1 commented "I found it interesting that our hypothesis was wrong. We made the hypothesis because the research we were doing [in reference to the PBL problem] was leading us to believe that exercise would slow down reaction time, but our own experiment showed that this was false".

Written Assignment Responses

Students did a formal writing response to the three sections of the PBL unit (Appendix V A-C). These assignments revealed a lot of student thinking and showed a wide range of understanding similar to the post-test written responses and lab responses.

Some students still had misconceptions. For example the muscle problem led one student to write "The marathon runner ran low on ATP, an energy chemical that helps muscles contract smoothly" (Student 5). Another example of a misconception is demonstrated when Student 17 concluded that "stress fractures in the leg bones let calcium out into the muscles and that caused muscle cramping".

Statements like these show that some students were hearing the language, and had some idea of what the science behind the topic was, but had fundamental misunderstandings. Calling ATP an "energy chemical" came up in the muscle writing response of four students. Also, many students seemed to have the idea that ATP played a small part in the overall process rather than being a key supplier of energy at multiple steps of the process. Class discussion covered ATP production and the role of glucose in great detail, but some students were missing this information.

Some students showed an intermediate understanding through their writing. For example, a student wrote "When myosin reached the end [of the actin filament] there was a buildup of myosin. This buildup led to the cramping" (Student 13). Statements like this show more understanding and are not all together wrong, but are still not really correct (myosin does not "buildup" at the end of the actin filament, but cannot detach due to low levels of ATP or an overload of calcium ions).

Still other students showed deep levels of understanding. Student #1 explained that "profuse sweating led to dehydration. The low water concentration in the blood and tissues drove up the concentration of sodium, potassium, and calcium. Sodium and potassium are critical ions in order to move nerve signals and calcium ions are critical in moving tropomyosin off actin allowing muscle contraction. This explains why our runner is having muscle cramps and is also having trouble with thought and reaction time".

While student #1's response was exceptional, many other students showed equal levels of comprehension of how these systems were related.

Survey

Upon completion of all three sections of the PBL unit, students completed a survey (Appendix VI-A).

Table 9: End of Unit Student Survey Item Analysis (*n* = 24)

Survey Question	Average Response	St. Dev.
1. Traditional teaching methods help me learn scientific concepts	4.3	0.7
2. PBL teaching methods help me learn scientific concepts	4.4	0.8
3. Traditional methods are more effective than PBL methods in helping me learn scientific information	3.1	0.8
4. I prefer developing my own questions to research and investigate rather than answering a question given to me by someone else	2.8	0.6
5. I find value in working with other students in a team to solve a problem.	3.3	0.6
6. Problem-Based Learning was more interesting than traditional methods	4.4	0.8
7. I feel that Problem-Based Learning will help information from this unit stay in my memory longer than traditional methods.	3.8	0.7
8. I feel that my understanding of bone and muscle anatomy and physiology is more complete than if I had read the information from a text book.	4	0.7
9. I think the lab activities in this unit aided in my understanding of the concepts covered in this unit	4.1	0.8
10. I prefer PBL to traditional classroom methods	3.4	0.7

Questions 1, 2, and 3 of the survey show that overall the students felt that PBL was an acceptable way to learn, but was not necessarily more effective (or less) than traditional methods.

Students found the process of developing their own questions to research difficult. The negative response to survey question 4 (A neutral response would have ranked a 3 and question 4 averaged a 2.8) was no surprise after having mediated the PBL 4-W sessions. Students would often get frustrated and would ask me to "just tell me what to research!" (Comment from student 10 during 4-W)

Survey questions 5 and 6 show an acceptance of the group collaboration format. Again, the results are not surprising after mediating the collaborative discussions. The students seemed to really enjoy bouncing ideas off one another. The only thing that frustrated them was deciding what questions should be researched and what questions were not relevant to the problem.

Survey questions 7 and 8 revealed students' feelings about retention of information. They seemed to be invested in the information they researched and retention was apparent as we continued the class.

Question 9 showed that students perceived the lab activities to be useful and relevant, although observing students in the lab environment would lead one to the opposite conclusion. As the lab activities stepped down in instructions, the students seemed less and less engaged. The muscle lab had all groups engaged all the time (and had step-by-step directions), the bone lab had more individuals sitting idle during the hour, (and had less direction from the instructor), and the nervous system lab had the most students seemingly disengaged (and had virtually no instructor directions). But, as discussed in the lab assessments, the students' lab writing did show good comprehension.

Question 10 showed that students did prefer the PBL method. The small degree of agreement may just be attributable to PBL being something new and different. It is difficult to say if the students actually preferred learning this way in comparison to traditional methods.

Discussion and Conclusion

This study sought to determine if PBL could be successfully implemented in a high school classroom, if PBL would show an increase in student understanding that can be measured with traditional forms of assessment, and if PBL would reflect other benefits to student learning that are less tangible than test scores.

All three foci of this study showed intriguing and promising results. With further study and analysis, it is believed that PBL may be an effective tool to add to secondary science education best-practice.

Can PBL work in a High School Classroom?

The limitations of a traditional high school classroom both in terms of time and number of students makes PBL a difficult fit. Consistent with the findings of Margaret Lohman and Michael Finkelstein, class size was one of the biggest challenges (Lohman and Finkelstein 2000). By dividing the class, it was possible to make collaborative groups that worked independently and then compiled information together at the end of the 4-W sessions. Their participation and intrest in the discussion was excellent as reflected by the results of the discussion participation rubric. While PBL would have an ideal student number of around eight students total, a large divided classroom was found to be manageable.

Time was the biggest factor. Western High School runs 55 minute class periods. Typically collaboration sessions would last nearly two full class hours resulting in an interrupted discussion. While students still had lively and engaging discussion, it took a few minutes at the beginning of each discussion hour to get back up to speed.

Student performance both in terms of grades and subjective observations were comparable to traditional units taught to the same group of students throughout the year. For example, the blood unit using non-PBL techniques immediately following this PBL unit resulted in a class test average of 82.2% and the circulatory non-PBL unit had a class test average of 78.6%. This is similar to test scores achieved during the three sections of the PBL unit (79.2%, 88.8%, and 94% being the class averages on the multipule choice sections of the PBL unit tests). Student performance on this PBL unit was also comparable to the performance of students in years past who were taught the same information with a traditional approach. However, the PBL unit required 37 days total, whereas the traditional versions of the same units in years past took 17 days. In order to make the PBL unit fit into the Anatomy and Physiology curriculum, some content was cut from a cellular biology unit earlier in the year. Since the curriculum for Anatomy and Physiology at Western High School is set by the teacher, this rearrangement of the course schedule was not a problem, but if PBL were to be incorporated into a course with a state-mandated curriculum, time management would be the largest obstacle.

Students were capable of finding legitimate scholarly articles. The issue was being able to sort relevant information from minutia. The instructor spent much of his time helping students sort and interpret the information they found. The students in this study had a very difficult time with scientific language in scholarly articles. This was apparent because the instructor could not move between groups fast enough to help fill in information students were struggling with.

Can a PBL unit result in adequate performance in traditional testing?

The objective data show that student understanding did increase due to implementation of this unit. Rote memorization was apparent from the increase in mean average of 58.8%, 43.3%, and 15.8% on the multiple choice portions of the three section tests within the PBL unit (see table 6). The average post-test scores during the PBL unit was 87.4% and showed little variation from test scores achieved by this group of students on non-PBL units. An issue to be considered, however, is the amount of time PBL takes to get to the same or similar test results when compared to more traditional methods. The PBL unit took twice as long to implement as the same content delivered using notes and lecture (31 days using PBL for a section that took only 17 days in years past using a didactic approach). If the only objective of high school education is to produce students who can perform adequately on standardized tests, this study shows that PBL is not a very efficient way to meet that goal. These findings are consistent with the findings of other studies (eg. Colliver's 2000) in which he writes:

> "The results are disappointing, providing no convincing evidence for the effectiveness of PBL, at least not the magnitude of effectiveness that would be hoped for with a major curriculum intervention. The results are also surprising, because the rationale for PBL is said to be based on educational theory and that theory is said to be supported by basic research. That is, PBL in contrast to the traditional lecture-based approach is thought to incorporate basic educational principles and to involve theoretical learning mechanisms, which presumably

should have a positive and sizable effect on the acquisition of basic knowledge and clinical skills." (Colliver 2000)

But my findings show gains in other areas besides performance on multiple choice test questions. In contrast to Colliver's findings, my study shows student gains in other respects. For example, average student scores on long answer test items during the PBL were high. The class average was above a 3 (on a 0-4 point scale) for all written response questions (see tables 7 and 8). These written responses show critical thinking skills in a way that is not apparent from multiple-choice, standardized test questions (see student quotes in post-test written response section) and point to some of the benefits to a PBL approach. Hmelo-Silver et al. (2007) arrives at a similar conclusion stating:

> "It is important to consider learning outcomes as multifaceted. The goals of learning should include not only conceptual and procedural knowledge but also the flexible thinking skills and the epistemic practices of the domain that prepare students to be lifelong learners and adaptive experts"

and she continues

> "students constructed more integrative explanatory essays for the concepts that they had learned using a PBL approach".

Hemlo-Silver (2007) refutes the findings of Colliver (2000) showing that PBL is more than a time consuming way of arriving at the same outcome, and parallels the findings of this study. PBL produces students that are not only prepared to perform on standardized tests, but are prepared to use new information and team-working skills throughout their lives.

Does PBL in a high school classroom have any benefits for student learning that traditional techniques do not address?

The results of this study show two major benefits that are not measurable by traditional means. First, students participating in the PBL unit were engaged in social interaction as a part of the problem solving process. This is a skill, and like any skill, it is strengthened with practice. The PBL forced students to compromise, negotiate, delegate, empathize with one another, and use decorum. The PBL unit more accurately mirrors how problem solving occurs in the workplace. While student performance measured with test scores is important, most educators would argue that preparation for the workplace is as important if not more important to education.

Another benefit of PBL was the practice students received with acquisition of primary source information. High school students typically have many scientific misconceptions gained from movies, television, and rumor. Educators can address some of these misconceptions using traditional teaching methods, but PBL gives students the tools to analyze information on their own. By the end of my PBL unit, I began to see scientific articles they found discussed with more skepticism. Students began to question source reliability. PBL makes students more interested in research and evidence to back up scientific information. My survey results showed students experienced frustration with determining what to research, but they were able to find valid scientific research. Once the students found information, they had pride in their findings and it fueled discussion (as was apparent from discussion observation rubric scores of straight 3 out of 3's).

Suggestions for future research: What went well

Future studies involving the implementation of a PBL unit may benefit from incorporating some of the ideas present in this study. One part of this study that went well was the running-themed PBL problems. Eight of the subjects in this study were cross-country runners and eighteen of the subjects were student-athletes. Because the topic was relevant to something the students experiences, they showed enthusiasm for the research and discussion. Oftentimes my students would relate findings to personal experience during discussion. My survey results (Table 9) showed students enjoyed the PBL format. Finding a subject that connects with students' personal experience was a key part to bringing PBL to the secondary level where motivation can be lacking.

The topic of athletic injury also led to great PBL problems. By their nature, a PBL problem should be ill-structured, meaning that there is no obvious solution and the research surrounding the problem may be conflicting or unclear forcing exploration and collaborative inquiry. Athletic injuries as part of a PBL led students towards many different avenues of research. Some student-generated research came from physicians and universities, some research came from corporate interests such as athletic shoe companies, sports drink companies, and medical equipment companies, and still other research supported holistic and non-traditional medicine. The wide range of bias and conflict present in the research helped build skepticism and lead to vigorous discussion in the PBL unit.

Suggestions for future research: What needs to be changed in future PBL units

There are difficulties in implementing a PBL unit at the secondary level. These problems would need to be addressed in future implementation of PBL in a high school. The first major problem was the number of students in my class. Dividing the students into small groups was effective to facilitate rich discussion within the groups, but it made it so the teacher was trying to direct three separate discussions, interpret research that the students were struggling with, take notes on student progress, and handle the day-to-day classroom routines at the same time. The teacher was exhausted by the end of every 4-W discussion. Managing twenty four students in a PBL is possible, but very challenging for the teacher.

Another interesting problem that occurred in the PBL unit was the issue of absences. In a traditional format, absent students miss an assignment or notes that can easily be acquired outside of class, but in a PBL format, absent students miss the collaboration that produces the class content. It is virtually impossible to re-create the discussion for absent students. Also, the rest of the class did not get the part of the information the absent student was supposed to bring back to the discussion. Fortunately, there were few student absences during this study, but every absence did require the teacher to spend time outside of class with the absent student in an attempt to get them up to speed on what they missed.

Both of these problems may be alleviated with more practice with PBL techniques. The teacher found that more practice implementing the technique quickly made a difference to his comfort level. Much like traditional teaching techniques, there is a learning curve to implementation of PBL and the only way to gain confidence is to use PBL with students in a classroom setting.

APPENDICES

Appendix I:

Student Scores

APPENDIX I-A

Muscular System Test Student Scores (*n* = 24)

Table 10

Student	Pre-test % Correct	Post-test % Correct	Difference (Post test - Pre-test)
S1	60	100	40
S2	10	60	50
S3	10	70	60
S4	20	90	70
S5	30	80	50
S6	20	90	70
S7	10	60	50
S8	20	90	70
S9	30	90	60
S10	0	60	60
S11	0	70	70
S12	10	90	80
S13	10	90	80
S14	20	80	60
S15	40	80	40
S16	10	40	30
S17	20	70	50
S18	40	90	50
S19	20	80	60
S20	30	80	50
S21	20	90	70
S22	20	80	60
S23	20	80	60
S24	20	90	70
Class average	20.4	79.2	58.8

APPENDIX I-B

Skeletal System Test Student Scores (n = 24)

Table 11

Student	Pre-test % Correct	Post-test % Correct	Difference (Post test - Pre-test)
S1	80	100	20
S2	30	60	30
S3	50	90	40
S4	50	100	50
S5	50	100	50
S6	30	90	60
S7	20	70	50
S8	60	90	30
S9	60	90	30
S10	50	100	50
S11	40	80	40
S12	50	100	50
S13	50	100	50
S14	50	100	50
S15	50	100	50
S16	10	70	60
S17	30	80	50
S18	70	90	20
S19	50	100	50
S20	60	70	10
S21	30	70	40
S22	20	80	60
S23	50	100	50
S24	50	100	50
Class average	45.4	88.8	43.3

APPENDIX I-C

Neuromuscular Junction Test Student Scores ($n = 24$)

Table 12

Student	Pre-test %	Post-test %	Difference (Post test - Pre-test)
S1	100	100	0
S2	40	80	40
S3	80	100	20
S4	80	100	20
S5	60	100	40
S6	80	80	0
S7	80	80	0
S8	80	100	20
S9	80	100	20
S10	100	100	0
S11	60	80	20
S12	80	100	20
S13	80	100	20
S14	80	100	20
S15	80	100	20
S16	40	60	20
S17	60	80	20
S18	100	100	0
S19	100	100	0
S20	60	100	40
S21	80	100	20
S22	100	100	0
S23	80	100	20
S24	100	100	0
Class average	78.3	94.2	15.8

Appendix II:

PBL Problems

APPENDIX II-A

Problem #1 part A

Jack is running his first marathon in New York City. He is excited to be running in the race and he feels pretty good as he passes mile marker 4 and grabs a cup of water from the volunteer standing by the side of the road. Jack's months of training are paying off. The conditions heading into this race were less than ideal and Jack was worried that he may not be able to finish.

As Jack makes his way through Brooklyn and passes into Queens, he begins to get an uncomfortable feeling in his gastrocnemius. He has felt this sensation before during his 18 week training regiment and he knows what it means.

As Jack passes the 14 mile mark, he grabs another water. He is breaking with his pre-race plan to take water only every four miles and decides to start taking water every two miles instead. He also chokes down another gu pack six miles ahead of schedule. He knows that the feeling in his gastrocnemius means race-ending muscle cramps are on the way. He hopes he can take some action to prevent them, but as he hits mile marker 16 on the bridge into Manhattan the muscles cramp and he is forced to stop.

Problem 1 part A for instructor:

Muscle sub-unit: Focus: Understand the sliding filament model of muscle contraction

Students will need to identify the four w's as I write them on the board:

1. What problem are we trying to solve?
2. What information is in the problem I have presented?
3. What do we already know about the subject from prior experience?
4. What do we need to find out?

#4 questions the instructor wants students to generate (perhaps some "leading" may be necessary!)

1. What is a muscle cramp?
2. What does water do for muscle cramps?
3. What is a gu pack and what might it do for muscle cramps?
4. What causes muscle cramps
5. What is a gastrocnemius?
6. Does training more reduce muscle cramping?
7. How do muscles work?

APPENDIX II-B

Problem #1 part B

Jack is standing on the 59th Street Bridge in agonizing pain. He tries to massage the tightened muscles, but the pain is all over his legs. It's as if all the muscles in his legs are contracting at once. Even his arm muscles are cramping.

He wishes he had taken the salt packet a volunteer had offered him back at the pre-race starting area. He is also regretting walking five miles the night before to get to a great pasta restaurant his sister wanted to go to. Speaking of his sister, he also wishes that she had brought the blankets she had said she would bring to the starting area so that he wouldn't have stood in the freezing cold shivering for two hours before the race started.

Jack knows he can't blame the cramps all on his sister. He also has a new baby at home and has not been sleeping well for the past few months. On top of that, he is pretty sure the months of training have given him a bone injury which may be a contributing factor to his muscle problem.

A race medic asks Jack if he is all right and gives him some Gatorade. After a few minutes of stretching and massaging, Jack thinks he can go on and begins running again.

Problem 1 part B for instructor:

Muscle sub-unit: Focus: Understand the sliding filament model of muscle contraction

Students will need to identify the four w's as I write them on the board:

1. What problem are we trying to solve?
2. What information is in the problem I have presented?
3. What do we already know about the subject from prior experience?
4. What do we need to find out?

#4 questions the instructor wants students to generate (perhaps some "leading" may be necessary!)

1. Why is the pain all over?
2. What do muscles run out of as you use them?
3. What part does salt, water, Gatorade play?
4. What part did cold and shivering play?
5. What does sleeping have to do with muscle cramping?
6. Do bones and muscles have any relationship?

APPENDIX II-C

Problem #2 part A

Jack has recovered from his muscle cramps for the time being, but as he heads into mile 20 of the marathon he feels a new problem developing. A throbbing pain in his tibia is getting worse. Jack knows he may have a stress fracture. He has felt it for many months leading up to this race, but he chose to ignore the pain rather than go to the doctor.

Now it's starting to feel like that was a bad decision. Perhaps the doctor could have done something to prevent the problem. Jack is certainly learning a lot about how NOT to run a marathon.

Jack wonders what the worst case scenario might be if he continues running and finishes the race. He has been running for three hours and he probably has at least another hour to go at this pace. The thought of dropping out of the race with only six miles to go is unbearable... but so is the pain coming from his tibia...

Problem 2 part A for instructor:

Bone sub-unit:

Focus: Understand bone deposition and reabsorption and bone physiology.

Students will need to identify the four w's as I write them on the board:

1. What problem are we trying to solve?
2. What information is in the problem I have presented?
3. What do we already know about the subject from prior experience?
4. What do we need to find out?

#4 questions the instructor wants students to generate (perhaps some "leading" may be necessary!)

1. What is a stress fracture?
2. What can be done to prevent it?
3. What are bones made of?
4. What can happen if you run on a stress fracture (displaced fractures)
5. How do bones respond to stress?
6. What is the treatment for fractures? Why does it work?

APPENDIX II-D

Problem #2 part B

Jack is very frustrated! This is not how he wanted this race to go. He is mad at himself for not taking some action to prevent stress fractures when he was training.

Jack's mom has always told him that calcium builds strong bones. Perhaps he should have been drinking more milk. Or Popeye was always eating spinach. That is supposed to be good for you. Could that help with bone strength?

Or maybe the bone is breaking because Jack is rather heavy for a runner. At 185 pounds, he is not chubby, but as he looks around at the other runners (who all look very happy and like their bones are NOT breaking), he notices that most of them are built small and light. Jack, on the other hand, is a little beefy for a runner. Jack wonders if it would have made a difference if he had dropped five or ten pounds before the race.

Or, Jack thinks, maybe he trained too much. Too much ground-pounding and the bone just couldn't take it any more... Or maybe he didn't train enough and the bone did not build itself up enough to deal with the stress. He followed a training regiment set up by a professional marathon runner. He was running about 40 miles per week near the end of his training.

Jack is worried about what this pain means. On the short term, he wonders if the bone problem might somehow be causing the muscle cramps (which he feels returning again). He remembered hearing that there is some sort of interplay between bones and muscles in his high school anatomy class... but he was too busy text messaging in class to remember much.

On the long term, Jack is worried about what might happen if the bone breaks all the way through. He knows that there is marrow in the bone that does some important stuff. Could a bad bone break screw up the rest of his body somehow?
All this worrying has made the miles seem to pass a little faster. Jack passes the 23 mile mark...

Problem 2 part B for instructor:

Bone sub-unit:

Focus: Understand bone deposition and reabsorption and bone physiology.

Students will need to identify the four w's as I write them on the board:

1. What problem are we trying to solve?
2. What information is in the problem I have presented?
3. What do we already know about the subject from prior experience?
4. What do we need to find out?

#4 questions the instructor wants students to generate (perhaps some "leading" may be necessary!)

1. What role does calcium play in a bone?
2. What role does general nutrition play (what is needed to make bone)?
3. What is the bone made of?
4. What effect does body weight have on bone?
5. What does repeated stress do to a bone?
6. How are bones and muscles related? Does one affect the other?
7. What is marrow? What does it do?

APPENDIX II-E

Problem #3 part A

Jack is ready to be done. Now at mile 24 of the marathon, his left tibia is screaming with pain and he has to stop every five minutes to massage his leg muscles to make the cramps go away. But he's so close! He can't stop now!

As Jack approaches another water station he begins to get a new sensation. He is finding it difficult to think clearly. He feels foggy in his head and he can't remember if he took water at the last station even though it was only fifteen minutes ago.

Suddenly, Jacks legs go completely out from under him. He manages to half fall, half sit down at the side of the road. His legs have stopped responding correctly. He can make his brain tell them to go, but the legs seem not to be getting the message.

This is a new problem. Jack sits for a minute and drinks some water...

Problem 3 part A for instructor:

Neuromuscular junction sub-unit:

Focus: Understanding how the nervous system communicates with muscles and the electro-chemical nature of nerve stimuli

Students will need to identify the four w's as I write them on the board:

1. What problem are we trying to solve?
2. What information is in the problem I have presented?
3. What do we already know about the subject from prior experience?
4. What do we need to find out?

#4 questions the instructor wants students to generate (perhaps some "leading" may be necessary!)

1. What does the brain need to function?
2. How do messages get from the brain to the muscles?
3. Will water help?

APPENDIX II-F

Problem #3 part B

After resting for several minutes, Jack is able to walk again. He eats some more gu and soon he is able to run again. At first it feels like it takes a moment for his brain to make his legs take each step. There is a noticeable lag between thinking about taking a stride and actually doing it.

He only has one mile to go now. That was a little scary. Bones and muscles are one thing, but when your brain gets screwy, you know you ran too much.

Jack wonders what caused his partial loss of consciousness and what he could have done to prevent it. He had been drinking plenty of water. The sugar gu seemed to help a little.

Resting for a moment also seemed to help. The end is so close now. He passes the half-mile to go sign. He gets a rush of adrenaline and suddenly feels much more clear-headed. His brain seems to be talking to his muscles instantaneously and normally again.

Finally, in just under 4 hours and 27 minutes, Jack crosses the finish line. And unlike the first guy that ran a marathon, it did not kill him!

Problem 3 part B for instructor:

Neuromuscular junction sub-unit:

Focus: Understanding how the nervous system communicates with muscles and the electro-chemical nature of nerve stimuli

Students will need to identify the four w's as I write them on the board:

1. What problem are we trying to solve?
2. What information is in the problem I have presented?
3. What do we already know about the subject from prior experience?
4. What do we need to find out?

#4 questions the instructor wants students to generate (perhaps some "leading" may be necessary!)

1. Why did water, sugar, and rest have an effect?
2. Why does the signal seem to be instantaneously getting from his head to his muscles and why wasn't it before? (chemical-electrical)
3. What does adrenaline do to the nervous system?

Appendix III:

Section Tests

APPENDIX III-A

Name:_______________________________ Date:_________ Hour:_______

Anatomy/Physiology Pre-Test: Muscles

_____1. **What is ATP?**

a. A type of muscle that contracts slowly.
b. A molecule used store energy in a quick, usable form in the body.
c. A long term energy storage molecule.
d. Adenosine tri-phosphate.
e. Both b and c
ab. Both b and d

_____ 2. **What is glucose?**

a. A type of muscle that contracts slowly.
b. A molecule used store energy in a quick, usable form in the body.
c. A long term energy storage molecule.
d. Adenosine tri-phosphate.
e. Both b and c
ab. Both b and d

_____ 3. **What process is your body using to make ATP molecules from glucose right now as you sit?**

a. Lactic acid fermentation
b. Photosynthesis
c. Chemosynthesis
d. Aerobic Respiration
e. Anaerobic respiration
ab. Because I am sitting, I do not need ATP right now.

_____ 4. **What is a neurotransmitter?**

a. A chemical your nerve cells use to communicate across a synapse.
b. Protease
c. Acetylcholine
d. All of the above are neurotransmitters
e. Both a and b are correct
ab. Both a and c are correct.

_____ 5. **Which is an example of an organ that is made of smooth muscle?**

a. The intestine.
b. The heart
c. The bicep muscle
d. All of the above
e. None of the above
ab. both a and c are correct

_____ **6. What is fascia?**

a. Connective tissue
b. This tissue surrounds the muscle fiber bundle and becomes a tendon near the end of the muscle.
c. It is tough and offers some protection to the muscle.
d. All of the above
e. None of the above
ab. b and c are correct.

_____ **7. Bones give skeletal muscles:**

a. A mechanical advantage by working like levers.
b. A hard surface for your muscles to push against.
c. Protection from the outside world.
d. A source of calcium ions that are important in contraction.
e. Both b and a are correct
ab. Both a and d are correct

_____ **8. Your skeletal "levers" :**

a. Never multiply the strength of your muscle contractions.
b. May multiply the distance of you muscle contractions.
c. Only allow your bones to move the distance that your muscle contracts.
d. Allows your muscle to use all of its energy to make force.
e. None of the above

_____ **9. What are the two kinds of myofibrils?**

a. Tendon and ligament
b. Aponeurosis and tendon
c. Periostium and Fascia
d. Actin and myosin
e. Motor neuron and motor end plate
ab. Z line and Nucleus

_____ **10. All of these chemicals are necessary to muscle contraction besides:**

a. Oxygen
b. Glucose
c. Calcium
d. Acetylcholine
e. Cholinesterase
ab. Myosin

APPENDIX III-B

Name:_________________________________ Date:__________ Hour:_______

<u>Anatomy/Physiology Test: Muscles</u>

_____1. **What is ATP?**

a. A type of muscle that contracts slowly.
b. A molecule used store energy in a quick, usable form in the body.
c. A long term energy storage molecule.
d. Adenosine tri-phosphate.
e. Both b and c
ab. Both b and d

_____ 2. **What is glucose?**

a. A type of muscle that contracts slowly.
b. A molecule used store energy in a quick, usable form in the body.
c. A long term energy storage molecule.
d. Adenosine tri-phosphate.
e. Both b and c
ab. Both b and d

_____ 3. **What process is your body using to make ATP molecules from glucose right now as you sit?**

a. Lactic acid fermentation
b. Photosynthesis
c. Chemosynthesis
d. Aerobic Respiration
e. Anaerobic respiration
ab. Because I am sitting, I do not need ATP right now.

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b. Protease
c. Acetylcholine
d. All of the above are neurotransmitters
e. Both a and b are correct
ab. Both a and c are correct.

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a. The intestine.
b. The heart
c. The bicep muscle
d. All of the above
e. None of the above
ab. both a and c are correct

_____ **6. What is fascia?**

a. Connective tissue

b. This tissue surrounds the muscle fiber bundle and becomes a tendon near the end of the muscle.

c. It is tough and offers some protection to the muscle.

d. All of the above

e. None of the above

ab. b and c are correct.

_____ **7. Bones give skeletal muscles:**

a. A mechanical advantage by working like levers.

b. A hard surface for your muscles to push against.

c. Protection from the outside world.

d. A source of calcium ions that are important in contraction.

e. Both b and a are correct

ab. Both a and d are correct

_____ **8. Your skeletal "levers":**

a. Never multiply the strength of your muscle contractions.

b. May multiply the distance of you muscle contractions.

c. Only allow your bones to move the distance that your muscle contracts.

d. Allows your muscle to use all of its energy to make force.

e. None of the above

_____ **9. What are the two kinds of myofibrils?**

a. Tendon and ligament

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d. Actin and myosin

e. Motor neuron and motor end plate

ab. Z line and Nucleus

_____ **10. All of these chemicals are necessary to muscle contraction besides:**

a. Oxygen

b. Glucose

c. Calcium

d. Acetylcholine

e. Cholinesterase

ab. Myosin

_____ **11. What doe the term "intercellular" mean?**

a. Inside cell

b. Outside cell

c. Near the center

d. Without cells

e. None of the above

_____ **12. Actin is**

a. A muscle group
b. A protein
c. A myofibril
d. Another name for a muscle cell
e. Both B and C are correct
ab. All of the above are correct

_____ **13. A muscle fiber is**

a. A muscle group
b. A protein
c. A myofibril
d. Another name for a muscle cell
e. Both B and C are correct
ab. All of the above are correct

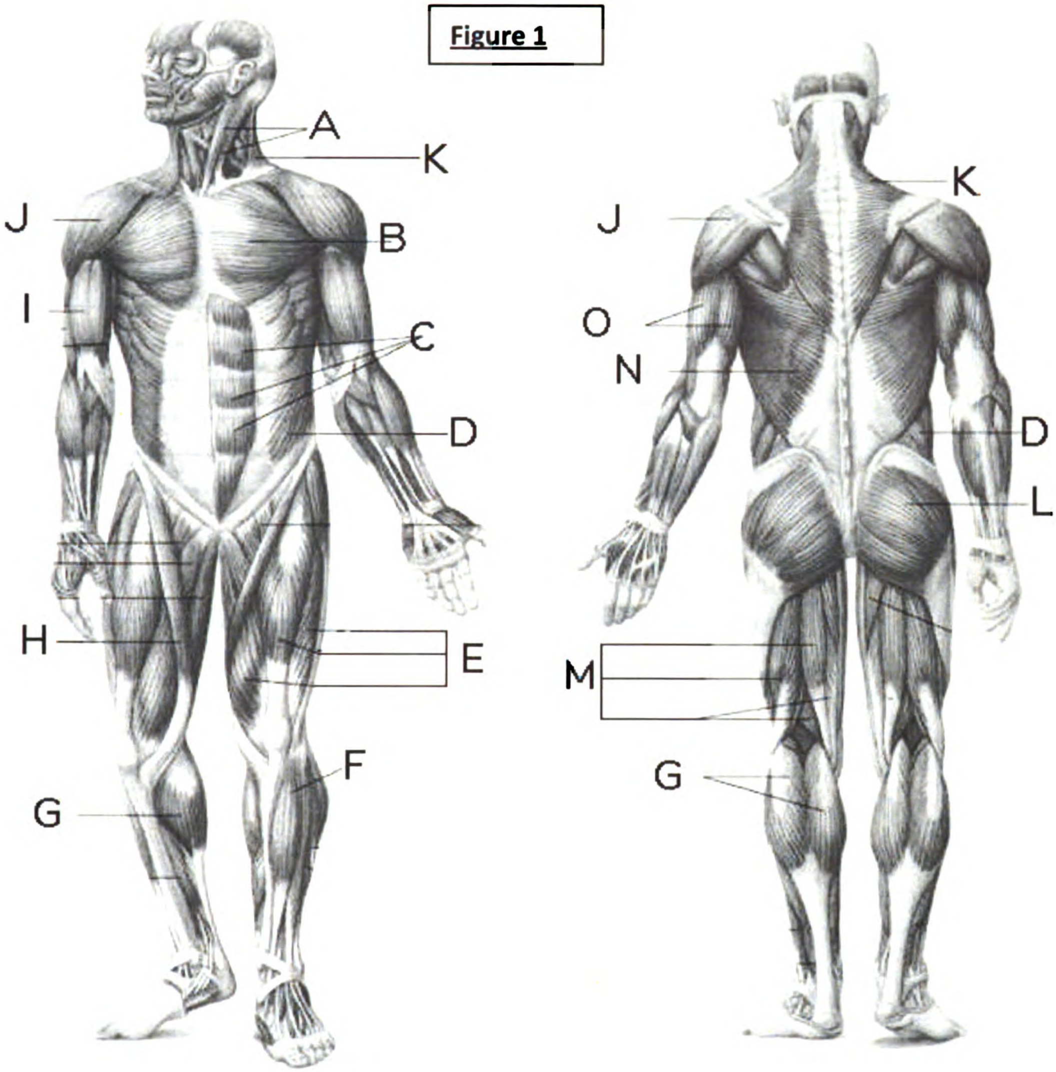
_____ **14. When a muscle cell is relaxed, where are the calcium ion's found in the highest concentration?**

a. Outside the muscle cell
b. Bonded to tropomyosin
c. In the sarcoplasmic reticum
d. In the blood
e. Both A and B are correct

_____ **15. Which of the following will NOT have an effect on the concentration of calcium ions in a muscle cell?**

a. More calcium is added to the cell
b. Calcium ions are removed from the cell
c. Water molecules are added to the cell
d. Water molecules are removed from the cell
e. Calcium ions move from inside the sarcoplasmic reticulum to the cytosol
ab. Options "c", "d", and "e" will not change calcium ion concentration in a cell
ac. Options "a" thorough "e" will all change calcium ion concentration in the cell

Figure 1



A:____
B:_______________________
C:____
D:_______________________
E:____
F:_______________________
G:____
H:______________________
I:____
J:_______________________
K:____
L:_______________________
M:____
N:____
O:____

Short Answer:
16. Write the basic chemical equation for respiration. (3 points)

17. List the three general types of muscles. Next to each, tell me where you might find these muscles. (3 points)

18. How do the three types of muscles differ in appearance? (3 points)

Essay

19. Describe the relationship between the prime mover, the synergist and the antagonist. (5 points)

20. Let's say you are lifting a dumbbell using your bicep muscle. Describe how the bicep muscle gets the message to perform the function. Start at with the message originating in your brain. (6 points)

21. Botox is an Acetylcholine inhibitor. Describe what Botox does to you in terms of the skeletal muscles of your face. (5 points)

22. Describe the process that creates usable ATP in your body. (6 points)

APPENDIX III-C

Chapter 7 Pre-Test: Skeletal System Name:____________________________________
Date:____________________ Hour:____________

____ **1. What is the epiphyses of a bone?**

a) The middle or "shaft" of the bone
b) The place where muscles will attach to bone
c) The part that is covered with cartilage and is at the end of the bones
d) The place where bone meets other bones
e) The part that makes up the hard outer shell of the bone
ab) The part that makes all the blood cells
ac) None of the above

____ **2. What is a joint?**

a) the middle or "shaft" of the bone
b) The place where muscles will attach to bone
c) The part that is covered with cartilage and is at the end of the bones
d) The place where bone meets other bones
e) The part that makes up the hard outer shell of the bone
ab) The part that makes all the blood cells
ac) None of the above

____ **3. What is the diaphysis?**

a) The middle or "shaft" of the bone
b) The place where muscles will attach to bone
c) The part that is covered with cartilage and is at the end of the bones
d) The place where bone meets other bones
e) The part that makes up the hard outer shell of the bone
ab) The part that makes all the blood cells
ac) None of the above

____ **4. What is the Bone Marrow?**

a) The middle or "shaft" of the bone
b) The place where muscles will attach to bone
c) The part that is covered with cartilage and is at the end of the bones
d) The place where bone meets other bones
e) The part that makes up the hard outer shell of the bone
ab) The part that makes all the blood cells
ac) None of the above

____ **5. Why do we have spongy bone?**

a) The soft bone absorbs shock.
b) The holes in spongy bone store water.
c) The holes in the bone make the bones lighter
d) The soft bone allows for more flexibility.
e) None of the above

____ **6. What does an osteoblast do?**

a) Breaks down bone
b) Protects the bone
c) Adds calcium to the blood
d) Builds new bone
e) Both "a" and "c" are correct

____ **7. What parts of the bone contain living cells?**

a) The marrow
b) The compact bone
c) The ends of the bone
d) The outer-most layer of a bone
e) All of the above

____ **8. What does a tendon do?**

a) Connects one bone to another
b) Connects one muscle to another
c) Connects a muscle to a bone
d) I holds organs in place
e) All of the above

____ **9. How does the body respond to a bone fracture?**

a) Osteoblasts begin to make new bone at the fracture site
b) The broken bone is removed by white blood cells
c) Osteoblasts break down the broken area of the bone
d) New bone will only be laid down if the person with the broken bone immobilizes the bone.
e) All of the above

____ **10. Which of the following is true of bone anatomy?**

a) Bones contain living cells
b) Bones are responsible for making blood stem cells
c) A process is the part of the bone where muscles attach to the bone
d) Bones are surrounded with a membrane
e) all of the above

APPENDIX III-D

Chapter 7 Test: Skeletal System **Name:**__________________________________

Date:___________________ **Hour:**____________

____ **1. What is the epiphyses of a bone?**

a) The middle or "shaft" of the bone
b) The place where muscles will attach to bone
c) The part that is covered with cartilage and is at the end of the bones
d) The place where bone meets other bones
e) The part that makes up the hard outer shell of the bone
ab) The part that makes all the blood cells
ac) None of the above

____ **2. What is a joint?**

a) the middle or "shaft" of the bone
b) The place where muscles will attach to bone
c) The part that is covered with cartilage and is at the end of the bones
d) The place where bone meets other bones
e) The part that makes up the hard outer shell of the bone
ab) The part that makes all the blood cells
ac) None of the above

____ **3. What is the diaphysis?**

a) The middle or "shaft" of the bone
b) The place where muscles will attach to bone
c) The part that is covered with cartilage and is at the end of the bones
d) The place where bone meets other bones
e) The part that makes up the hard outer shell of the bone
ab) The part that makes all the blood cells
ac) None of the above

____ **4. What is the Bone Marrow?**

a) The middle or "shaft" of the bone
b) The place where muscles will attach to bone
c) The part that is covered with cartilage and is at the end of the bones
d) The place where bone meets other bones
e) The part that makes up the hard outer shell of the bone
ab) The part that makes all the blood cells
ac) None of the above

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b) The holes in spongy bone store water.
c) The holes in the bone make the bones lighter
d) The soft bone allows for more flexibility.
e) None of the above

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e) All of the above

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a) Bones contain living cells
b) Bones are responsible for making blood stem cells
c) A process is the part of the bone where muscles attach to the bone
d) Bones are surrounded with a membrane
e) all of the above

____ **11. What is Compact Bone?**

a) The middle or "shaft" of the bone
b) The place where muscles will attach to bone
c) The part that is covered with cartilage and is at the end of the bones
d) The place where bone meets other bones
e) The part that makes up the hard outer shell of the bone
ab) The part that makes all the blood cells
ac) None of the above

____ **12. What is a Process?**

a) The middle or "shaft" of the bone
b) The place where muscles will attach to bone
c) The part that is covered with cartilage and is at the end of the bones
d) The place where bone meets other bones
e) The part that makes up the hard outer shell of the bone
ab) The part that makes all the blood cells
ac) None of the above

____ **13. What are the joints that hold your skull together called?**

a) Skull joints
b) Sutures
c) Osteons
d) Ball and socket
e) Condyloid
ab) None of the above.

___ **14. What is the lower part of your spine (between your hip bones) called that is made of fused together vertebrae?**

a) Coccyx
b) Sacrum
c) Lumbar
d) Spinal cord
e) Calcanious

___ **15. What is heel bone called?**

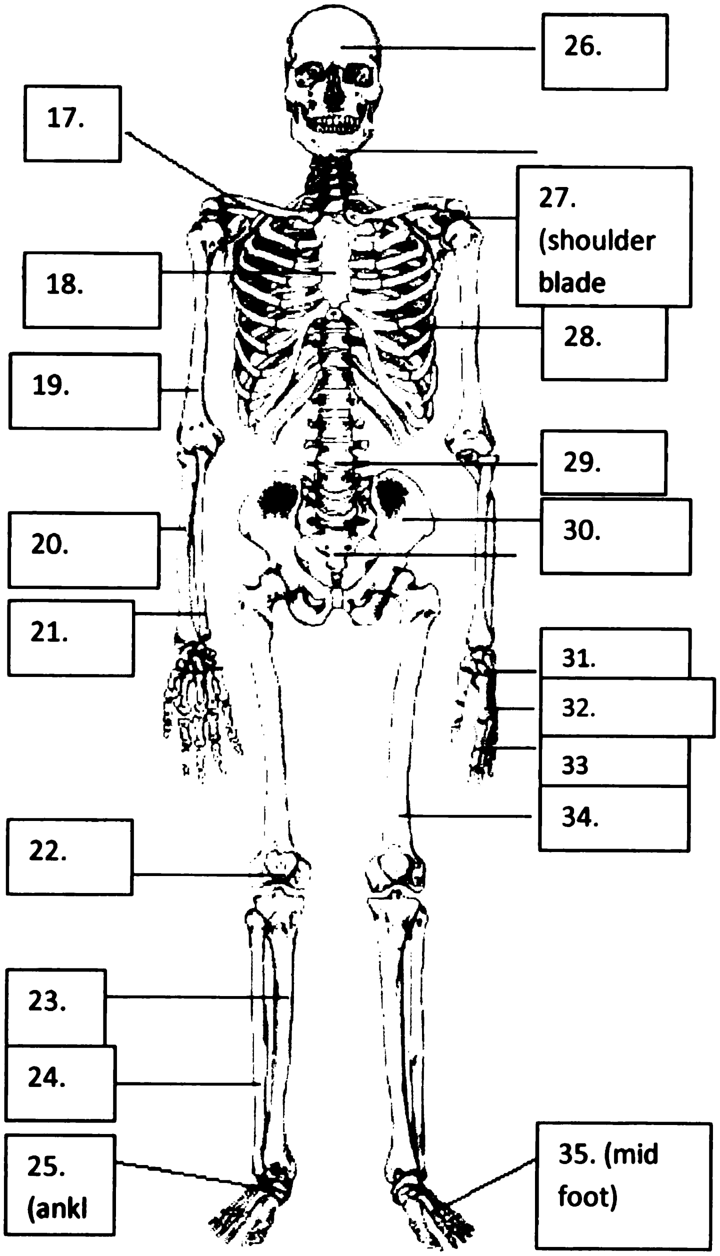
a) Coccyx
b) Sacrum
c) Lumbar
d) Spinal cord
e) Calcanious

____ **16. What is the "tail" bone called?**

a) Coccyx
b) Sacrum
c) Lumbar
d) Spinal cord
e) Calcanious

For 17 – 35 , identify the parts of the skeletal system

Figure 2



a) Cranium
b) Patella
c) Phalanges
d) Scapula
e) Ulna
ab) Radius
ac) Metatarsals
ad) Femur
ae) Fibula
abc) Rib
abd) Tibia
abe) Clavicle
acd) Sternum
ace) Metacarpals
abcd) Carpals
abce) Tarsals
abcde) Humerus
bc) Vertebra
bd) Pelvic bones

Short Answer:

36. What are the three regions of the spine called and where are they found? (3 points)

37. Describe the two types of cells found in and around compact bone. What do they both do? (2 points)

38. What are four functions of the skeletal system? (4 points)

Essay Questions:

39. Describe some common problems people have with bones. (5 points)

APPENDIX III-E

Name:________________________ Date:____________________
Hour:_______________

Neuro-muscular junction pre-test

1. A neuron is also known as:

a) A nerve cell

b) A muscle cell

c) A bone cell

d) A blood cell

e) None of the above

2. A neurotransmitter is:

a) Used in order to produce an electrical charge

b) Powers myosin filaments

c) A chemical that carries a message across a synapse

d) Another word for a calcium ion

e) All of the above

3. Water plays an important part in biology because:

a) It is a polar molecule

b) It is a solvent in which many other molecules can be dissolved

c) It plays a part in making and breaking many chemical bonds

d) It resists changes in temperature

e) All of the above

4. Tissues throughout the body respond to __________ signals

a) Chemical

b) Electrical

c) Light

d) "a" and "b" are correct

e) None of the above

5. How fast do signals travel from your brain to your leg muscles?

a) At the speed of light

b) Very fast, but nowhere near the speed of light.

c) Very slowly, but most of the distance is skipped thanks to electron transport chains.

d) It can vary depending on chemicals present (or absent) in your blood.

e) "b" and "d" are correct.

APPENDIX III-F

Name:_________________________ Date:____________________
Hour:________________

Neuro-muscular junction post-test

1. A neuron is also known as:

a) A nerve cell

b) A muscle cell

c) A bone cell

d) A blood cell

e) None of the above

2. A neurotransmitter is:

a) Used in order to produce an electrical charge

b) Powers myosin filaments

c) A chemical that carries a message across a synapse

d) Another word for a calcium ion

e) All of the above

3. Water plays an important part in biology because:

a) It is a polar molecule

b) It is a solvent in which many other molecules can be dissolved

c) It plays a part in making and breaking many chemical bonds

d) It resists changes in temperature

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4. Tissues throughout the body respond to __________ signals

a) Chemical

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d) "a" and "b" are correct

e) None of the above

5. How fast do signals travel from your brain to your leg muscles?

a) At the speed of light

b) Very fast, but nowhere near the speed of light.

c) Very slowly, but most of the distance is skipped thanks to electron transport chains.

d) It can vary depending on chemicals present (or absent) in your blood.

e) "b" and "d" are correct.

Appendix IV:

Laboratory Explorations

APPENDIX IV-A

Name:______________________________ Date:__________________
Hour:_________

Controlled Muscle Contraction and Fatigue

Introduction:

Any time you move, your body shortens ***skeletal muscles*** to move your bones. This shortening is possible because of a complex series of interactions between ***protein filaments***, ***ions***, ***enzymes***, ***oxygen***, ***glucose***, and ***ATP***.

With repeated use of a muscle group, your muscles run low on necessary components of the contraction reaction. Fortunately, you have many muscle groups that act as ***synergists***. These synergist muscle groups can take over more of the work load as the ***prime mover*** becomes less able to contract.

For example, you may notice that if you ride a bike for a long period of time, your muscles become increasingly uncomfortable. If you shift your body position on the bike, you are able to continue riding at roughly the same speed and your muscles are more comfortable than they were. Slight changes in body posture and position change which muscle groups are doing the most work.

In this lab, we will isolate one small muscle group and not allow synergistic muscles to aid in the contraction. We will make observations and record data in order to better understand how our muscles fatigue. We will make conclusions as to how and why the adaptation of synergist muscles came to be.

Learning the Language:

Make sure you can use the following words. Write definition for the following terms in your own words. Give an example where appropriate.

Skeletal Muscle:

Protein Filaments:

Ion:

Enzymes:
Oxygen:

Prime Mover:

Glucose:

ATP:

Synergist:

Lab Materials:

-Muscle Isolation Box
-Pencil
-Paper

Procedure:

Set up:

1. Assign one member of your group the record keeper and the other as the test subject

2. The test subject should be sitting comfortably in arms reach of the isolation box. Once the test subject is seated comfortably it is important not to change the position of the test subject or the box.

3. The test subject will put on the muscle isolation glove. Notice that there are dots drawn on the isolation glove and that your fingers are restricted.

4. The test subject will put his/her hand in the muscle isolation box. Inside the box is a switch made from a clothespin. The test subject needs to put his/her hand on this clothespin so that the dots on their glove touch the dots on the pin. This ensures that the subject always has their hand in exactly the same position.

5. The record keeper will place a hand on the top of the isolation box to hold it steady. Make sure the position of the box does not change during the entire procedure.

Experiment and data collection:

6. Both group members should wait for Mr. Rissi to say "Go". The test subject should squeeze the clothespin until the "at rest" light goes out and the "full contraction" light turns on. Then the test subject should release the clothespin and repeat this motion as many times as possible.

7. The record keeper should be focusing on the lights on the top of the box. Every time the "full contraction" light turns on, the time keeper will need to count the contraction. In order to be sure the test subject is performing full contractions, the record keeper needs to ensure the "full rest" light is coming on between contractions. If it does not, the next contraction does not count.

8. At the end of 40 seconds, Mr. Rissi will say "Stop". The test subject can rest. The record keeper should record the number of full contractions in table 1 below.

9. Repeat this procedure 12 times.

10. Switch roles, and repeat the procedure again.

Table 13:

	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Trial 6**	**Trial 7**	**Trial 8**	**Trial 9**	**Trial 10**	**Trial 11**	**Trial 12**
Test subject #1												
Test subject #2												

Results:

Using graph paper, graph you and your partner's data on one graph.

Interpreting Results:

Answer the following:

1. What trends do you see in your graph? Make a hypothesis concerning why this trend is happening.

Conclusions:

2. As the numbers on your graph go down, what is happening inside each muscle fiber (cell)?

3. During the 20 second rest between each trial, what is going on inside your body?

4. Why was so much care taken to make sure the test subject or the box did not move? Why did we use the box? Why not just have a clothespin? Is this good science? Why or why not?

5. Predict what would happen if you were allowed to change the position of your hand at trial #6. Why would this happen?

6. Let's say you want to be the world's clothespin squishing champion. What sorts of things could you do to increase your performance? What would happen to your muscle physiology if you did these things?

APPENDIX IV-B

-In order to control muscle movement during the Controlled Muscle Contraction and Fatigue lab, a devise was constructed that limited the test subject's arm movement during the lab and lit a light bulb every time a full range of motion was achieved. The light bulb insured full contraction of the muscle group being observed and also allowed the recorder to count light blinks to ensure more accurate data collection. The directions and diagram below demonstrate how the devise was built:

Materials:

1. One #4 5" or 6" machine screw and nut.
2. One spring-type clothespin.
3. One board (1/2" x 4" molding strips work well) cut into 4" sections (with beveled 45° joints if you want to be fancy and have a miter saw handy)
4. Aluminum foil
5. Small gage wire
6. AA battery
7. Flash light bulb
8. Wood glue
9. Drill with 1/8" bit
10. One sheet of cardboard

Construction (refer to figure 3 on next page):

1. Make a box from the cut board sections.

2. Secure the box to the center of the cardboard using glue with the open end facing the user.

3. Drill 1/8" hole through horizontal axis of the box (a). Drill another hole in the top of the box (b).

4. Glue aluminum foil to the ends of the clothespin (f).

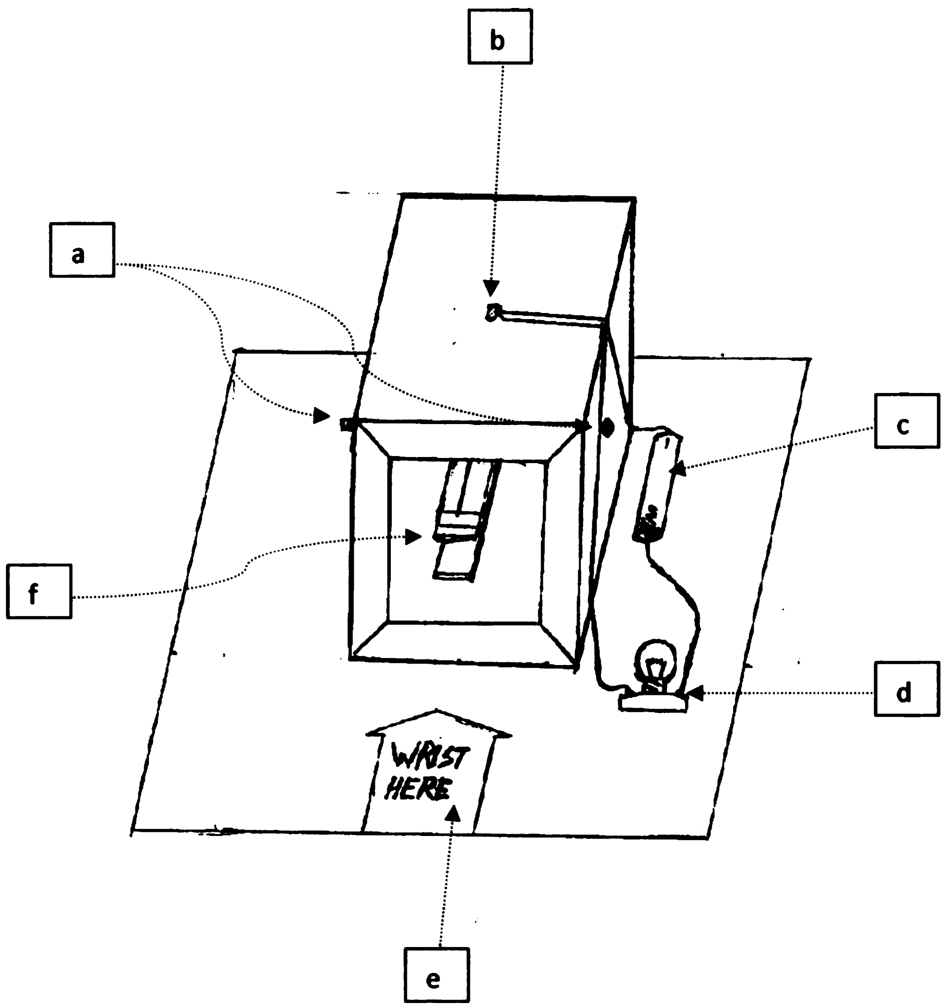
5. Insert the clothespin into the box and secure by running the machine screw through the drilled hole on the left side of the box (a), then through the clothespin spring, then through the right side of the box (a) and use the nut to secure it in place.

6. Run wires from the aluminum covered ends of the clothespin and up through the top of the box. One wire should contact a battery glued to the cardboard (c). The second wire should contact one lead of the flashlight bulb (d).

7. Use a second wire to attach the remaining lead of the light bulb (d) to the other end of the battery(c). When the clothespin is pinched, the light bulb should light if the wiring is done correctly.

9. Draw an arrow indicating where the test subject's wrist should rest (e).

Figure 3



APPENDIX IV-C

Name:_________________________ Date:___________ Hour:_________

Bone Dissection and Density Analysis Lab

The bone is made of living tissue. In order to better understand the anatomy of a bone, we will be cross sectioning a bone, examining its structure, and measuring its density.

Step A: Bone preparation:

1. If your teacher is feeling nice, he will prepare a long leg bone from an animal. To do this, first the bone must be boiled for several hours to remove most of the fat from inside and outside the bone.

2. The bone will then need to be soaked in a bleach solution in order to further break down fats and proteins. This will also sterilize the bone.

3. The bone will then need to be scrubbed with an abrasive pad to remove any remaining flesh from the bone.

Step B: Examine the external structure of the bone:

1. Examine the outside of the bone. Look in your book at the picture on page _________. Draw your bone below as it looks right now and label the parts:

-Proximal Epiphysis

-Distal Epiphysis

-Diaphysis

-Articular cartilage

Step C: Label and Cross Section:

1. Draw 7 even lines on the bone with a permanent marker. Number the sections 1-8. Add these lines to your drawing above.

2. We will now attempt to section the bones along these lines. I have no idea how challenging this might be. We will do our best. Try your best to follow the lines drawn on the bone.

Step D: Examine your section:

1. Examine and draw your cross section below. Label the parts:

-Compact bone

-Marrow cavity

-Spongy bone

2. Using the stereoscope examine the compact bone. Record your observations below.

Step E: Find the density:

1. Using the triple beam balance, find the mass of your bone section.

2. Using the large graduated cylinder, find the volume of your section.

3. Find density by dividing mass by volume

   m / v = __________

4. Record your density on the board.

Step F: Interpret our results:

1. What does our bone density map tell us about the anatomy of bones?

APPENDIX IV-D

Name: ____

Reaction Time Investigation

In order to better understand what sorts of factors affect the nervous system and its communication with muscle tissue, you will design an investigation.

You may wish to use reaction timers provided. One person will need to activate the timer with the thumb switch. The red light on top of the box will light when the timer starts. The test subject will need to step on the foot switch the moment they see the red light activate.

The digital readout on the box will show the test subject's reaction time.

Journal Write After Completion

1. What was the hypothesis of your investigation and what did you do to test the hypothesis?

2. What was the result of your investigation?

3. Did you find working in a group challenging? What did you like about working as a class and what did you not like?

Appendix V:

Written Assignments

APPENDIX V-A

Name:________________________ Date:__________________
Hour:_______________

PBL Problem 1 Write Up: Muscles

Answer the following questions in complete sentences. Please type your responses. These responses are due _________________________

1. Describe what you think caused our runner's muscle cramp? What is a cramp? Make sure to include how a normal muscle contraction works and contrast that to how a cramped muscle is functioning.

2. What could our runner do to prevent muscle cramps in the future? Why would these preventative measures work?

3. Did any factors in the PBL problem not play a significant role?

APPENDIX V-B

Name:_______________________ Date:__________________
Hour:_______________

PBL Problem 2 Write Up: Bones

Answer the following questions in complete sentences. Please type your responses. These responses are due _______________________

1. What caused our runner's stress fracture? Make sure you describe the structure of a healthy bone and what has gone wrong in order to produce a stress fracture.

2. What can be done to prevent stress fractures? Why would these preventative measures be helpful?

3. What are some other bone injuries? Compare and contrast any you can think of.

4. What are at least three different jobs bones do? Explain these jobs. Show me that you understand how bones play a part in other systems of the body.

APPENDIX V-C

Name:________________________ Date:__________________

Hour:_______________

PBL Problem 3 Write Up: Nervous System and Muscles

Answer the following questions in complete sentences. Please type your responses. These responses are due _________________________

1. Why is our runner having problems now? How does a normally functioning nerve impulse compare to what is happening in our runner now?

2. What role does water play?

3. What ions are important when making your body move? Why?

Appendix VI:

Survey

APPENDIX VI-A

PBL Opinion Survey

Please take a moment to fill out this survey concerning your experience with the PBL unit we have just completed. Your answers will be kept strictly confidential. Circle your response.

1. Traditional teaching methods help me learn scientific concepts.

5-Strongly Agree 4-Agree 3-Neither agree nor disagree 2-Disagree 1-Strongly disagree

2. PBL teaching methods help me learn scientific concepts

5-Strongly Agree 4-Agree 3-Neither agree nor disagree 2-Disagree 1-Strongly disagree

3. Traditional methods are more effective than PBL methods in helping me learn scientific information

5-Strongly Agree 4-Agree 3-Neither agree nor disagree 2-Disagree 1-Strongly disagree

4. I prefer developing my own questions to research and investigate rather than answering a question given to me by someone else

5-Strongly Agree 4-Agree 3-Neither agree nor disagree 2-Disagree 1-Strongly disagree

5. I find value in working with other students in a team to solve a problem.

5-Strongly Agree 4-Agree 3-Neither agree nor disagree 2-Disagree 1-Strongly disagree

6. Problem-Based Learning was more interesting than traditional methods

5-Strongly Agree 4-Agree 3-Neither agree nor disagree 2-Disagree 1-Strongly disagree

7. I feel that Problem-Based Learning will help information from this unit stay in my memory longer than traditional methods.

5-Strongly Agree 4-Agree 3-Neither agree nor disagree 2-Disagree 1-Strongly disagree

8. I fell that my understanding of bone and muscle anatomy and physiology is more complete than if I had read the information from a text book.

5-Strongly Agree 4-Agree 3-Neither agree nor disagree 2-Disagree 1-Strongly disagree

9. I think the lab activities in this unit aided in my understanding of the concepts covered in this unit

5-Strongly Agree 4-Agree 3-Neither agree nor disagree 2-Disagree 1-Strongly disagree

10. I prefer PBL to traditional classroom methods

5-Strongly Agree 4-Agree 3-Neither agree nor disagree 2-Disagree 1-Strongly disagree

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