ENHANCING GRAPHICAL LITERACY SKILLS IN THE HIGH SCHOOL SCIENCE CLASSROOM VIA AUTHENTIC, INTENSIVE DATA COLLECTION AND GRAPHICAL REPRESENTATION EXPOSURE

By

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ABSTRACT

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This research project was developed to provide extensive practice and exposure to data collection and data representation in a high school science classroom. The student population engaged in this study included 40 high school sophomores enrolled in two microbiology classes. Laboratory investigations and activities were deliberately designed to include quantitative data collection that necessitated organization and graphical representation. These activities were embedded into the curriculum and conducted in conjunction with the normal and expected course content, rather than as a separate entity. It was expected that routine practice with graph construction and interpretation would result in improved competency when graphing data and proficiency in analyzing graphs.

To objectively test the effectiveness in achieving this goal, a pre-test and post-test that included graph construction, interpretation, interpolation, extrapolation, and analysis was administered. Based on the results of a paired T-Test, graphical literacy was significantly enhanced by extensive practice and exposure to data representation.

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INTRODUCTION

Rationale and Statement of Problem

In the evolving world in which we live, the body of scientific knowledge is continually growing as researchers across the globe investigate various systems and seek resolutions to questions and problems. Each discipline becomes seemingly more compartmentalized as each investigator's focus becomes more specific to their related research field. Thus, a crucial dynamic in the scientific community is effective collaboration and communication. To digest this continual stream of progressive research, it is desired that this communication be condensed into a convenient form. The "language" of science often involves data representations including charts, tables, diagrams, and graphs that offer an analyzed and summarized version of an investigation. In describing graphs, one researcher says, "They present concepts in a concise manner or give at glance information which would require a great deal of descriptive context" (as cited in Berg and Smith, 1994). In many contexts, graphs can be considered communicative devices (Padilla, McKenzie, and Shaw, 1986). Experts of the scientific discipline become well-versed at constructing, dissecting, and analyzing these types of communicative data representations. Many important scientific discoveries and understandings are not immediately recognized. Rather, these findings are identified by careful analysis of data. When unorganized, data tend to be awkward and difficult to comprehend. Graphs, however, force us to see important or unusual details that we never expected (Friel, Curcio, and Bright, 2001).

One overarching goal of a dedicated science educator is to build disciplinary literacy and subject-specific knowledge and comprehension. In conventional terms, literacy refers to reading and writing proficiencies. However, in the discipline of science one must also consider the importance of data collection, data representation, and data analysis as it applies to understanding the process of science and perhaps to the comprehension of specific concepts. In fact, experts propose that "using graphical representations are critical to being scientifically literate" (Coleman, McTigue, and Smolkin, 2011). The graphs themselves are representations of quantitative scientific information and serve as tools in detecting patterns which inform the viewer about the phenomenon that is under investigation (Roth and McGinn, 1997). Clearly, in a discipline that relies on empirical, quantitative evidence, establishing proficiencies with graph construction and interpretation could be considered essential.

Scientific literature and even high school textbooks provide evidence of the importance of visual representations such as graphs in conveying information. In a random survey, it was determined that, on average, there are 1.46 to 1.38 graphics per page in typical scientific journals and high school science textbooks (McTigue and Flowers, 2011). Graphs are excellent tools for depicting quantitative data and make it easier to understand a scientific concept (Shah and Hoeffner, 2002). Of course, this assumes that the viewer has the capability of analyzing the information contained within (Tairab and Khalaf Al-Naqbi, 2004). Research has consistently shown that students of all ages have difficulty comprehending graphs and this lack of proficiency "is a handicap and a limiting factor in learning scientific concepts" (Ates and Stevens, 2003).

Significant effort has been put forth in attempting to find cause for this general lack of competency with regard to graphical literacy. It has been argued that interpretation and even graph construction skills require abstract reasoning ability. Thus, some researchers are resolute that abilities related to graphing proficiencies are dependent on developmental cognitive abilities (as cited in Friel et al., 2001). These researchers might insist that it is entirely expected that young learners, those in elementary and middle school, are incapable of constructing and analyzing certain graphs effectively. Traditional research in science shows graphing as a compilation of individual abilities and skills, and graphs themselves serve as mental representations to the learner (Roth and McGinn, 1997). In the tradition of the Piagetian philosophy, the lack of proficiency many students have with graph construction and interpretation can be attributed to the learner lacking “logical-thinking structures”. Support for this reasoning is reinforced by research that demonstrate the correlation between sixth, seventh, and twelfth grade students’ logical reasoning ability and graphing achievement (as cited in Roth and McGinn, 1997).

However, others argue that graphing proficiencies are not “exclusive” to cognitive ability. Like many other skills, meaningful practice is necessary before one can be expected to master and become proficient at graphing. Logically, some argue that students who are not exposed to experiences requiring graph construction or evaluation will certainly not be good at it (Friel et al., 2001). Some argue that individuals need a certain level of knowledge *before* they are able to legitimately participate in practicing graphing (Roth and McGinn, 1997). This sort of reasoning does not appeal to the educational practitioner who is interested in systematically assisting students and working with them in skill development. Proponents who view graphing ability as a “practice driven” process insist that if students are expected to acquire graphing competence they surely must “participate actively in the development and maintenance of this practice” (Ibid).

Reasonably, it can be assumed that practice would positively impact the acquisition of a desired skill. This belief is fundamental in the premises behind the study reported here. In the arena of science education it is valid to ask the question: How much “meaningful” graphing practice are students exposed to during a general K-12 education? Beginning with the elementary level, self-contained classroom teachers typically do not have extensive preparation in the discipline of science. Furthermore, visual representations, in general, have played a minor role compared to other forms of communication, including written and oral. In a comprehensive study involving the self-reported use of graphical representations in elementary science teaching, researchers concluded that elementary “teachers are not likely to employ graphical representations to their fullest potential when teaching science” (Coleman, McTigue, and Smolkin, 2011). The practice involving graphs that does exist can be considered limited in frequency and in complexity. Furthermore, the skills and cognizant thought processes needed to analyze graphical representations is generally not taught explicitly. Thus, there is a distinct possibility that a typical student does not receive the exposure required to cultivate these skills needed for effective graph construction and analysis.

One would think that the aforementioned prevalence of graphical representations in scientific literature and high school textbooks would provide significant amounts of practice and exposure to a typical student. However, it has been pointed out that “Textbook examples of graphs often are too pre-processed” (Friel et al., 2001). When the purpose of graphical representations and their precise role in a science text is considered, it is understandable that these graphs are deliberately designed to be “processed” easily. Obviously, graphs embedded in a text are provided to assist with comprehension of whichever topic or concept is contained within that section. Indeed, significant efforts have been made to determine which factors in graph design might contribution to enhanced comprehension.

Researchers have concluded that, when designing graphs for ease of integration into one’s knowledge base, the “number of cycles of processing required to interpret the graph” should be minimized (Ratwani, Trafton, and Boehm-Davis, 2008). The dual nature of graphs is to teach and present data. There are two general considerations relative to the learner’s analysis of a graph – visual integration and cognitive integration. With respect to visual integration, it is suggested that "visual clusters" of information in texts be presented so that they can be easily framed. The boundaries of various features of the graph should be highlighted or bolded such that they are perceptibly distinct to the viewer. Even the selection of color needs to be intentional when designing a graph to facilitate visual integration. "Spectral color palettes" that are easy to discriminate should be incorporated rather than minor adjustments in shading or intensity (Ratwani et al., 2008).

Likewise, designing graphs for efficient cognitive integration also requires calculated attention to design details. Researchers have concluded that "graphs should be designed to reduce the amount of processing needed to reason with the visual clusters formed during visual integration" (Ratwani et al., 2008). Intuitively, one understands that when a graph is overly complex it requires the viewer to transition between the various regions and features contained within the representation. More complicated graphs inherently depend on additional cycles of visual integration and cognitive integration (Ratwani et al., 2008). As these transitional requirements increase, it is more likely for the student to make processing errors. It is also possible that when graphs contain too many intricacies the cognitive load presented might be beyond the ability of the viewer.

When considering the implications of graph cognition research, it is understandable that textbook publishers carefully choose how data should be represented. For integration and assistance with understanding, graph simplification is the general theme. In a comprehensive review of the research, it was determined that "Non-informative features are unhelpful and often distracting" and certain unnecessary features that have been categorized as "chart junk" should be minimized (Shah and Hoeffner, 2002). It is even suggested that some traditional features, such as graph keys and legends be eliminated. These features “require that graph readers keep referents in memory” and “pose special demands on working memory” (Shah and Hoeffner, 2002). An implication has been that, if possible, graph features should be labeled directly, rather than using an auxiliary key or legend.

The careful considerations involved in selecting graphical representations for textbooks are an indirect acknowledgement that students have difficulties with graph comprehension. In the educational community, however, the relevance of graphs is also presented directly. State benchmarks and National Science Education Standards emphasizing graphical literacy serve as evidence that skills related to graphing are understood and valued (Coleman et al., 2011). Review of the Michigan Department of Education’s Grade Level Content Expectations (version 1/09) and High School Content Expectations (version 10/06) reveal that data organization, analysis, and comprehension are universally critical for each respective content discipline (physics, chemistry, biology, and earth science). The inclusion of graphical literacy in content expectations is entirely justified because it is unlikely students will develop such skills unless they are directly addressed by the curriculum (Padilla et al., 1986).

Of course, in the domain of public education, the ultimate importance of any skill might be gaged by how this ability translates into achievement on standardized tests. After all, student achievement on standardized tests determines the meeting of Adequate Yearly Progress (AYP) in conjunction with the much discussed *No Child Left Behind* legislation. When viewed in this light, the importance of developing graph construction and analysis skills is highlighted once again.

Researchers investigating how necessary diagrammatic literacy skills are for success on standardized tests exposed some remarkable statistics. In the analysis of 985 standardized test questions collected randomly from various state assessments for late-elementary to middle school grade levels, researchers discovered that 52.7% of test questions involved graphical representations (Yeh, and McTigue, 2009). Of these questions involving graphics, 79.5% of the representations contained information needed in successfully answering the question. The most prevalent types of representation included graphs and data tables, and the frequency of such representations was found to increase as students advance in grade level. Thus, a student's ability to proficiently extract information and meaning from graphs is imperative if success on standardized tests is expected.

Recently, there has been a concern that students in this country are falling behind and our nation will lose its innovative identity and competitive edge in the disciplines of science and engineering. Thus, the development of "critical thinking" skills has been advocated and recognized as a priority in the future of the educational system. Those researching the development of critical thinking skills and their assessment believe that a more multidisciplinary approach that includes the analysis of visual representations is necessary (Malamitsa, Kokkotas, and Kasoutas, 2008). The interpretive skills needed for effective critical thinking are intimately connected to all forms of literacy, including that which is graphical. Using a standardized assessment tool, The Test for Everyday Reasoning (TER), researchers analyzing various age groups determined "a strong relationship" between graph and chart interpretation and the assessed critical thinking skills (Ibid). Thus, it is advocated that visual literacy, which includes graph interpretation, should be taught in conjunction with critical thinking. Researchers warn that teachers often assume visual representations are "self-explanatory" and that students can decipher them without being provided any support (Ibid).

With this in mind, intentional instruction regarding graph analysis is required to develop graphical literacy that will enhance critical thinking (Fencl, 2010). In one study, "carefully designed" hands-on experiences which incorporated graphing resulted in significant gains in the critical reasoning skills of university students (Fencl, 2010). A curricular experience with embedded practice and routine use of graph analysis skills resulted in students being able to apply the same skills in a "straightforward but unfamiliar" situation (Fencl, 2010). The crossovers of such abilities are conditional on intentionally designed activities and the skill must be practiced repeatedly. The implications of this are particularly important to classroom teachers – a curriculum designed with these considerations can produce students that are capable of applying graph analysis skills to the frequent instances encountered on standardized tests and college entrance exams.

One might question why exactly "intentional" practice is necessary for the acquisition of these skills, especially to those that translate to standardized test achievement. The considerations involved in the design of representations to assist with graph comprehension have been detailed extensively. However, the motives involved in graph implementation on standardized tests, compared with those in textbooks, appear as a conflict. Obviously, textbooks attempt to enhance comprehension, while standardized tests seek to assess skills, abilities, and understanding. Rather than intentionally simplifying graphs, standardized tests are likely to incorporate graphs which pose visual and cognitive obstacles. Graphs, charts, and tables on the ACT, for example, often require the student to evaluate and cross-reference multiple figures when answering a question. Likewise, standardized assessments often present multifaceted graphs that include multiple data sets and relate several variables at one time. For instance, graphs displaying three continuous variables are seldom encountered by a typical student, and consequently, reflect a complex analysis task (Friel et al., 2001). As the complexity of the graphs increases, it requires students to internalize many different referents, increasing the time and processing required while evaluating the representation (Ratwani, 2008). As one would expect, children and even adults are likely to "make systematic errors interpreting graphs, especially when graphs do not explicitly depict the relevant quantitative information" (Shah and Hoeffner, 2002).

When it comes to graphical analysis, it is important to understand specifically what challenges students when evaluating graphs. Generally, students perform better when they are assessed on the ability in identifying a "specific piece of interpretations" that are directly indicated by the graph (Tairab and Khalaf Al-Naqbi, 2004). For example, in a graph of population growth students are typically capable of recognizing the maximum population value, or they can identify when the population grew at the greatest rate. However, students demonstrate relatively poor skill when interpreting graphs in a quantitative manner and making broad descriptions of what a graph is communicating. Finally, researchers have determined that students lack an understanding of the different types of data representations (Tairab and Khalaf Al-Naqbi, 2004). Thus, students are unaware of when and how various graphs are used to display quantitative information.

The capabilities demonstrated in graph interpretation are not equal among different types of representation. For students, reading and analyzing circle graphs, or pie charts, tends to be a less challenging task (Ates & Stevens, 2003). Bar graphs also tend to be easier for students to decipher, and the writer has noted that middle school and high school students tend to have an inclination to favor this type of representation. The author speculates that in earlier educational experiences, bar graphs were probably most likely to be employed. It is ventured that over-emphasizing one type of representation “may lead students to conceive all graphs as having that form” (Meverech and Kramarsky, 1997). Perhaps the propensity for bar graphs also relates to the fact that line graphs tend to be the most difficult for students to interpret. It has been proposed that the construction and interpretation of line graphs requires “abstract reasoning skills” (Padilla et al., 1986). Obviously, line graphs are preferred when attempting to depict trends and changes rather than simple comparisons and the use of line graphs is extensive in the scientific domain.

Since little can be done regarding the specific cognitive ability of a student, the logical approach would include support in developing these “abstract reasoning skills” related to graphing. As elaborated, much research has been dedicated to the reading and interpretation of graphs by students. Friel and others explain that few researchers have explored other considerations, including “graph construction or invention or graph choice” (2001). Very little is understood how statistical laboratory investigations that include graph creation relates to students’ comprehension. Researchers speculate that instruction within an appropriate context “may promote a high level of graph comprehension that includes flexibility, fluid, and generalizable understanding of graphs and their use” (Friel et al., 2001). The outright implication, therefore, is that students who are engaged in formulating graphical representations are likely more prepared to convey their understanding of represented data, relating it to other information, and successfully answering questions that are posed (Friel et al., 2001).

When engaging students in authentic laboratory investigations, the learners at least have some perspective and understanding of context – and they understand how the data were collected and what the data are attempting to represent. One study that illustrates the importance of contextual knowledge involved having research scientists analyzing graphs that were unrelated to their own precise discipline. In this study, researchers determined that “One’s extensive interaction with phenomenon and representational means seems to be prerequisite for competent graphing practices” (Roth and Bowen, 2001). The conclusion, therefore, is that students need more than just instruction that focuses on the mechanical construction aspects of graphing. Instead, the graphical representation should be tied directly to occurrences that they are familiar with.

Generally, standardized assessments are delivered in a multiple-choice format. Given this reality, one might assume that direct and frequent exposure to existing standardized-test style graphs and subsequent questions would be the most efficient strategy for developing learners’ measured graph comprehension skills. Tairab and Al-Naqbi, while studying tenth grade science students’ competencies with graphs, recognized that students tend to perform better at interpretation tasks in comparison to the constructive processes (2004). The suggestion from this research is that teachers ought to specifically practice construction and interpretation in unison. Students should be exposed to “varied and rich” activities that involve graphing data. Other researchers also identify value in having students construct graphs, because it provides enhancements in their examination capabilities. Berg and Smith (1994) venture that “perhaps the act of construction leads to higher levels of cognitive engagement by forcing students to attend to the local processes”. Therefore, the environment of an effective science classroom should unite the progressions of data collection, graph construction, and corresponding critical analysis.

Another important consideration that one must ponder is that graph construction and graphical analysis skills are not isolated and unique to the scientific discipline. Obviously, graphs are intimately tied to the field of mathematics, but graphs can also be encountered in other traditional high school courses including those such as social studies and history. Thus, incorporation of graphing into a science curriculum might also pay dividends by teaching processing skills that can be applied in multiple subject areas. This proposition has been supported by research. In a comprehensive study examining graphing ability, grade school students tended to do well on determining appropriate X and Y coordinates and point plotting. This exhibited proficiency, some speculate, was due to the fact that these skills overlap into the science and math curriculums and have been emphasized early in the student's educational experiences (Padilla et al., 1986). Hochberg and Gabric go as far as describing math and science as a "provably necessary symbiosis" (2010). These researchers developed overlapping biology and math lessons, with the mathematical, qualitative components being "interwoven" into the science concepts under investigation. Not surprisingly, graphing was included in these activities. Other practitioners seek to use graphing in other unique and interesting ways. The strategy of "creative graphing" is an activity that allows students to organize and represent information graphically. This method can occur in multiple curricular settings, even those involving writing and literature. One proponent explains that the process of re-organizing complex information into appropriate graphs is a highly effective learning strategy for many students (Johnson, 1989). Certainly, an interdisciplinary perspective that cultivates graphical literacy in multiple subject areas can be entirely warranted.

The rationale for this research project includes a novel approach: Including authentic data collection and graph construction into a science curriculum with the expectation that students' proficiency with graphical representation will improve. With the incorporation of laboratory activities that generate authentic data, it is expected that learners will develop a sense of "ownership" for the data they collect, thereby establishing a realistic context for graphing practice to be conducted. During the course of a laboratory investigation, having students experimenting and collecting their own data inherently makes them familiar with the context (Friel et al., 2001). Researchers have recognized that a viewer's knowledge of context influences their ability in scrutinizing and making sense of graphs (Shah and Hoeffner, 2002). Thus, the approach employed in this study ensures all students will be familiar with the concept being investigated, the setup and organization of the laboratory apparatus, and the methodology used in collecting data.

The researcher considered developing an independent unit of study that focused entirely on graph construction and analysis, without the inclusion of curricular content. However, this approach would provide disruptions in the host school's accepted curricular scheme and sequence. It can be noted that this was the researcher's first experience teaching the respective courses in which this study was implemented. Because the author had never taught these courses, seamlessly embedding the developed activities, rather than retooling the entire curriculum, was a logical approach. In addition, based on the conclusions of experts, the chosen inclusive approach to teaching graph construction skills and analysis was justified.

The extensive practice and exposure to graph construction embedded within the content of a biology course is aligned with the suggestions of experts. Shah and Hoeffner, following their review of graph comprehension research, decided that "Graphical literacy skills should be taught in the context of science" (2002). Obviously, students can not be expected to tacitly acquire graph comprehension knowledge, and researchers suggest that explicit instruction with graphical representations should be entrenched within authentic, scientific inquiry (Coleman, 2011).

Teachers of science in the K-12 setting are encouraged to mimic the scientific process by including genuine laboratory investigations. However, it is the experience of the writer that often times the quantitative element of collecting empirical evidence is ignored. Many times, “lab activities” rely on subjective observations rather than the analysis of concrete, quantitative data. Understandably, some investigations are difficult to quantify, or the equipment needed for quantification is too expensive and or unavailable to the typical educator. Thus, for this study, activities that generate data that could be quantified, graphed, and analyzed using ordinarily available materials were developed. The approach of this study is to provide authentic, intensive data collection experiences and routine exposure to graph construction and graph analysis problems. Fundamentally, the author expects that student-constructed graphs accomplished in the context of learning science will also provide the most legitimate opportunities for graphical analysis. It is hypothesized that exposure to authentic data collection and routine graphing practice will positively support improvements in students’ measured graphical literacy skills. The null hypothesis is that these efforts will have no effect.

Class Descriptions and Demographics

This study was administered at Avondale High School within the Avondale School District, a suburban community located approximately 21 miles north of Detroit, Michigan. The Avondale District spans across multiple municipalities, including portions of Auburn Hills, Bloomfield Township, Rochester Hills, and Troy. Avondale High School has a student population of approximately 1160 students and includes a diverse student body composed of 65% White/Caucasian, 21% Black/African American, 8% Asian/Pacific Islander, 5% Hispanic, and 1% Multiracial. Approximately 24% of students qualify for free or reduced lunch and Avondale High School receives Title I funding. Average class sizes included 26 students for the 2011-2012 school year, and the graduation rate was reported at 97% for 2010-2011. Of those, 72% of students attended college directly after graduating. ACT scores for the 2011-2012 school year included an average composite of 21.2, and 21.7 for the science portion.

At Avondale High School the biology curriculum is split into two separate semester courses, “Microbiology” and “Macrobiology”. The framework for each course’s curriculum is structured based on the Michigan Department of Education’s High School Content Expectations for Biology (rev. 10/06). Content expectations are appropriately divided and distributed into each course. This research project was initiated in two separate Microbiology classes during the first semester of the school year. Each class was composed mostly of tenth grade sophomores, but a few high-achieving ninth grade freshman students were also present. Both classes included special education students that qualified for accommodations.

At the beginning of the semester, consent forms were distributed and students were given a timeframe of approximately 2 weeks to return them. In addition, during an introductory open house, visiting parents were made aware of this study. In the first class section, 21 of 25 students consented and in the second section 19 of 22 students provided consent. This established a participation of 85% of enrolled Microbiology students, which can be considered a highly representative sample

IMPLEMENTATION

General Considerations

During the preparation of this study and development of activities contained within, there were some uncertainties regarding the teaching schedule that the writer would undertake. A potential transfer to the district's middle school was a distinct possibility that was thoroughly considered. Thus, concepts that provided opportunities for graphing were selected such that activities could be modified and translated into the seventh grade curriculum if needed. It was determined that osmosis, photosynthesis, cellular respiration, and enzyme activity were concepts that lend themselves to quantitative analysis and presented overlap in both curriculums.

The range of concepts investigated spanned approximately 9 weeks of academic instruction. Thus, each activity was strategically implemented into each respective unit of study at the most opportunistic and logical time. In general, these activities were implemented with the learner already having some background knowledge provided by other planned curricular activities and perhaps some prior learning experiences. Again, the approach was not to drastically alter the ebb and flow of the accepted curriculum, but rather to embed these authentic, data-intensive laboratory investigations that required graph construction and analysis. Table 1 illustrates the unit-by-unit break down and specifies which activities were developed for the project reported here. After each activity, laboratory worksheets were collected, assessed, and returned to students. Particular attention was applied to graphs which were constructed. Individual students might receive specific comments that corresponded to the graph they submitted. Also, while assessing student submissions, the instructor kept note of common errors that signified conceptual errors or processing deficiencies. Upon returning graphs and laboratory worksheets to students, the instructor methodically described these consistent errors. Examples of common errors were illustrated or projected onto the board such that students could self-evaluate their own graphs. In some instances, exemplars were displayed in each class to model appropriate use of scale and graph organization.

Before engaging in any planned graphing activities, the pre-test that included two separate components was administered. Each part of the pre-test was administered on two separate but consecutive days. This decision was made due to time considerations and to avoid testing fatigue. The pre-tests were conducted during the second week of school, during the first unit of study. All enrolled students completed this test before consent forms were returned.

Table 1: Incorporation of Graphing Activities into the Curriculum
The respective conceptual units of study and the particular graphing activities that were embedded within each. A brief description of each graphing task is also included.

Unit of Study	Embedded Activities	Description of Graphing Tasks
UNIT I Scientific Processes "Chemistry of Life"	Investigation #1 (Grow Toy) *How does dissolved salt concentration affect the change in size (length) and mass of a grow-toy?*	A 2-line graph that incorporates 2 independent y-axes (± % change in length and mass). X-axis – % Salt concentration (*m/v*)
UNIT II "Cells"	Investigation #2 (Osmosis in Potato and Cantaloupe) *A comparison of the osmolarity of potato and cantaloupe. Determining what would be considered a hypotonic or hypertonic solution for each. Using the constructed graph to determine isotonic concentrations for each cell type and testing this prediction.*	A 2-line graph that incorporates ± % change in mass on the y-axis and potato and % Sucrose concentration (*m/v*) on the x-axis. This is a unique task because it includes positive and negative values on the y-axis.

Table 1 (cont'd)		
UNIT III "Cellular Respiration and Photosynthesis"	Investigation #3 (Photosynthesis Lab – Bubble Rate) *Determining how intensity (distance from light source) and the color of light (wavelength) affects the photosynthetic rate of an aquatic plant.*	2 separate graphs (one that relates to intensity and the other wavelength). Each graph includes 2 separately graphed lines. The slope of each line representing the rate of photosynthesis
UNIT III "Cellular Respiration and Photosynthesis"	Investigation #4 (Photosynthesis Lab – Disk Assay) *Determining how the availability of carbon dioxide affects the rate of photosynthesis. (Addition of sodium bicarbonate)*	A 2-line line graph that compares the photosynthetic rate (with a supplied carbon dioxide source and without)
	Investigation #5 (Respiration Rate – Yeast) *Testing the respiratory rate of yeast when exposed to various sugar concentrations at a standardized temperature. Rate determined by measuring CO_2 production via the movement of an "indicator" in a small diameter tube.*	A line graph that includes multiple lines (Variable % sugar concentrations)
	Investigation #6 (Lactic Acid Buildup) *Subjects squeezing a tennis ball with their non-dominant hand until fatigued related to aerobic and anaerobic respiration*	A bar graph that compares the results of various students participating in the activity
UNIT III/IV	Investigation #7 (Enzyme Activity – Temperature and pH) *Investigating how pH and temperature influence the digestion of starch by the enzyme amylase*	One graph comparing the % starch digested (y-axis) at various temperatures (x-axis). Another graph comparing the starch digested in different pH solutions

Discussion and Analysis of Activities

Investigation #1 (Grow Toy) – (Appendix A)

During the first unit of study, as is typically done in many science courses, a general overview of the scientific method was presented to students. The dynamic nature of the scientific process was studied and students engaged in various activities to recognize many relevant skills, such as observation, question generation, and measurement. However, there were not any existing activities that incorporated graphing. The "Grow Toy" investigation was included towards the end of the first unit because it provided a general review of the scientific method and it required the use of these tangible skills. For the purposes of this study, it provided the first real, authentic investigation that included data collection and graphical representation.

To facilitate and streamline the execution of this investigation, tap water was pre-mixed with precise amounts of sodium chloride to establish the required salt concentrations (2.5%, 5.0%, 7.5%, 10.0%, and 15.0%). Large containers of distilled water and each solution were provided to students, relevant measurements were made, and "Grow-Toys" were soaked in each respective solution for 24 hours. The following day, students removed the toys, dried them, conducted post-soaking measurements, and calculated respective changes in mass and length. These mathematical calculations posed a significant challenge for several students. However, working in collaborative groups supported those who struggled.

Students were instructed to construct a graph that represented both the changes in mass and the changes in length. This necessitated that students utilize two separate y-axes, one for the percent change in mass and the other for the percent change in length. Figure 1 is a student example produced during this activity. Since this was the first exposure to this type of

Figure 1: Investigation #1 Exemplar

This investigation necessitated 2 separate Y-axes – one for the change in mass and the other for the change in length. Different scale values allowed students to recognize that the changes in both parameters were closely related. For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.

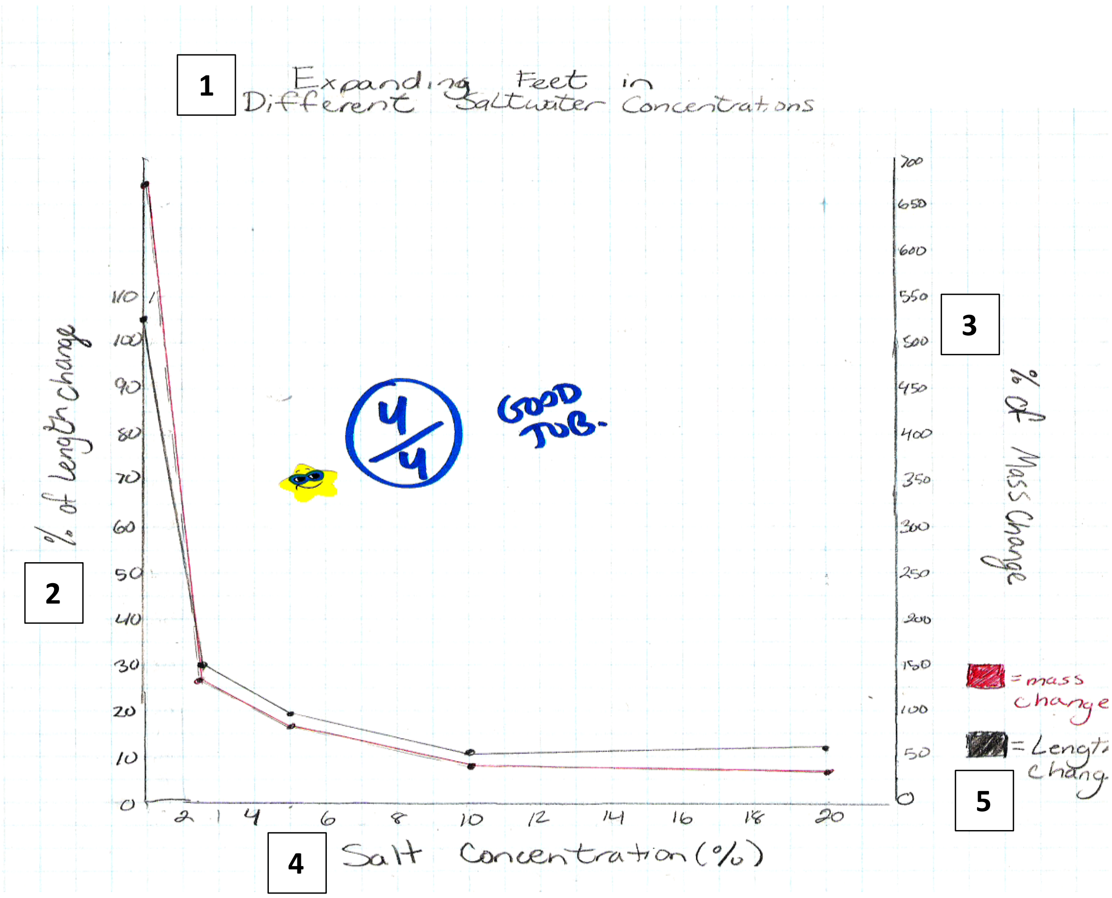


Figure Legend:

1. **Graph Title**
2. **Left Y-axis - % change in length**
3. **Right Y-axis - % change in mass**
4. **X-axis - % salt concentration**
5. **Graph key**

representation, it was expected that students might struggle. Some direct instruction to scaffold the graph construction process was provided as well as some individual instruction to struggling students.

On the initial pre-test students had a tremendously difficult time with the construction of a similar graph. Thus, this graphing exercise made them aware of how a graph can be designed to deal with multiple variables. One common mistake noted by the instructor was errors in the scale utilized on the X-axis. Although the salt concentrations were conveniently chosen, these increments were not uniform. Many students made conceptual errors in equally spacing data points horizontally (even though the data is not quantitatively spaced equally). After assessing each student's submission, graphs and laboratory worksheets were returned, the common mistakes were explained, and exemplars were provided for reference.

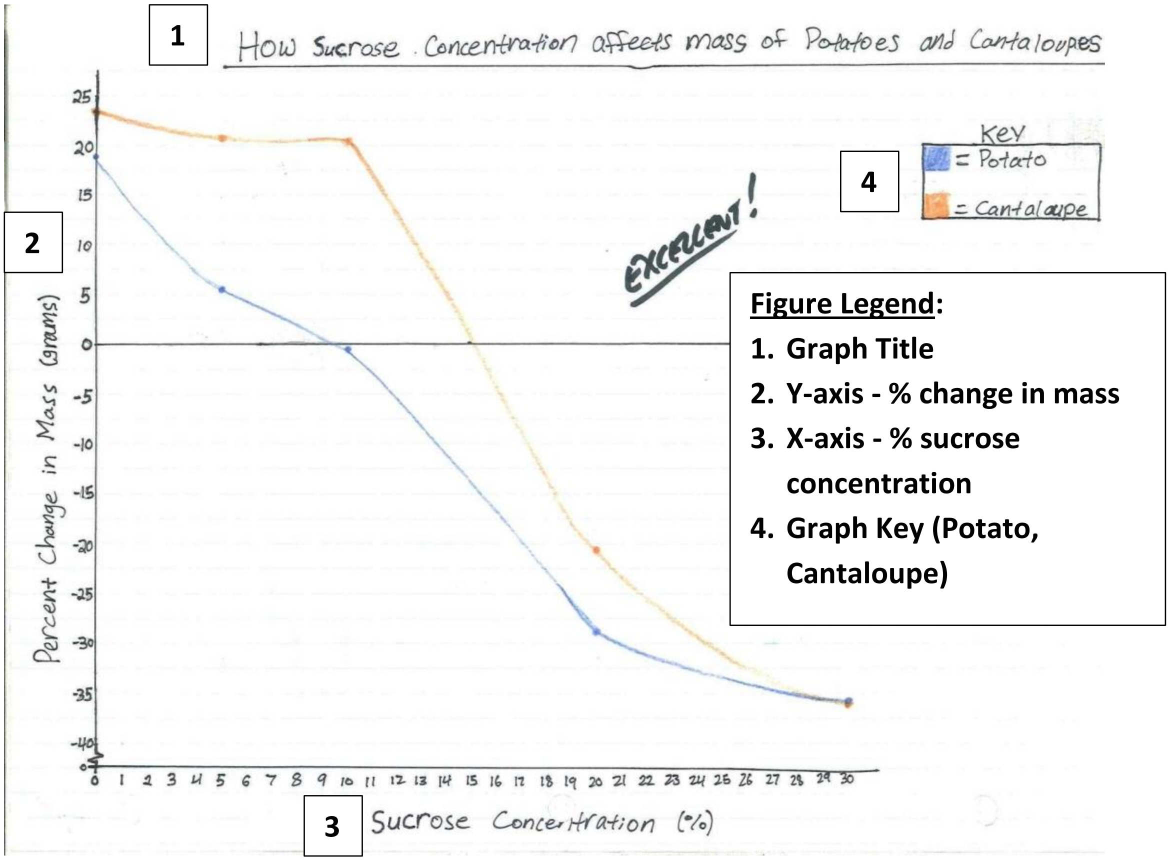
Investigation #2 (Osmosis in Potato and Cantaloupe) – (Appendix A)

The second unit of study focused on cells and incorporated the concepts of molecular movement across cell membranes. Specifically, the concept of osmosis was investigated. In a prior laboratory activity, students quantitatively analyzed osmosis via a popular activity – subjecting an egg to a hypertonic solution (corn syrup) and hypotonic solution (distilled water). Although this investigation provided some practice with data and provided insight into the concept, it did not include any data representation. It was logical, therefore, to build on prior knowledge and segue into a more structured, data-intensive examination of osmosis.

Different concentrations of sucrose (5%, 10%, 20%, and 30%) we pre-mixed by the instructor. Due to the limited time allotted per class period, such preparatory steps were done for logistical considerations. Students in selected laboratory groups cut potatoes using a vegetable cutter to ensure consistency in size. Similar to Investigation #1, students measured the initial

Figure 2: Investigation #2 Exemplar

The graph produced in this investigation was unique because it needed to include both positive and negative values on the Y-axis.



mass of each sample and then soaked a sample in each respective solution (with variable sucrose concentrations). Because of cost considerations, each group did not repeat this procedure with the cantaloupe. Instead, the instructor conducted the process with the cantaloupe and gathered a "classroom data set" that all groups could use and evaluate.

The following class period, samples were removed, dried, and measured, and percent changes in mass were calculated. The instructor used the cantaloupe sample as an opportunity to model how to conduct the measuring and calculation process. As a class, the calculations were performed for the cantaloupe so that students could use these data in their graphical analysis.

Although difficulties were encountered, the researcher noted that there seemed to be fewer struggles (in comparison to Investigation #1). Students then were tasked with organizing and representing both data sets (potato and cantaloupe) onto a single graph. One unique aspect of this investigation is that, depending on the sucrose concentration, some samples gained mass while others lost mass. Therefore, it was necessary for students to construct a graph that allowed for the graphing of negative values on the y-axis. A student-produced example is provided in Figure 2.

Using their constructed graphs, students answered a variety of post lab questions (See Appendix A). In addition, students were asked to use their graphs in predicting an isotonic solute concentration for each sample type. This concentration corresponded with the respective line's intersection of the X-axis. Several predictions were solicited from students and solutions were mixed to test these predictions. It was determined that student predictions were accurate in establishing an approximately isotonic concentration.

Investigation #3 (Photosynthesis Lab – Bubble Rate) – (Appendix A)

The third unit of study provided the best opportunity to incorporate data-rich laboratory activities. The concepts of photosynthesis and cellular respiration lend themselves to laboratory investigations. In this first laboratory exercise investigating photosynthesis, students were distributed into collaborative groups. The groups were then divided such that some groups investigated how light intensity affects the photosynthetic rate of an aquatic plant. The remaining groups investigated how the color of light affects the photosynthetic rate. The laboratory apparatus was set up similar to how it is illustrated in Appendix A. However, instead of using a separate heat sink, the test tubes were submerged in a large beaker of water, a strategy that

Figure 3: Investigation #3 Exemplar

Different laboratory groups were assigned to test one of the investigated variables. Afterwards, groups shared data and graphed the results from both experiments

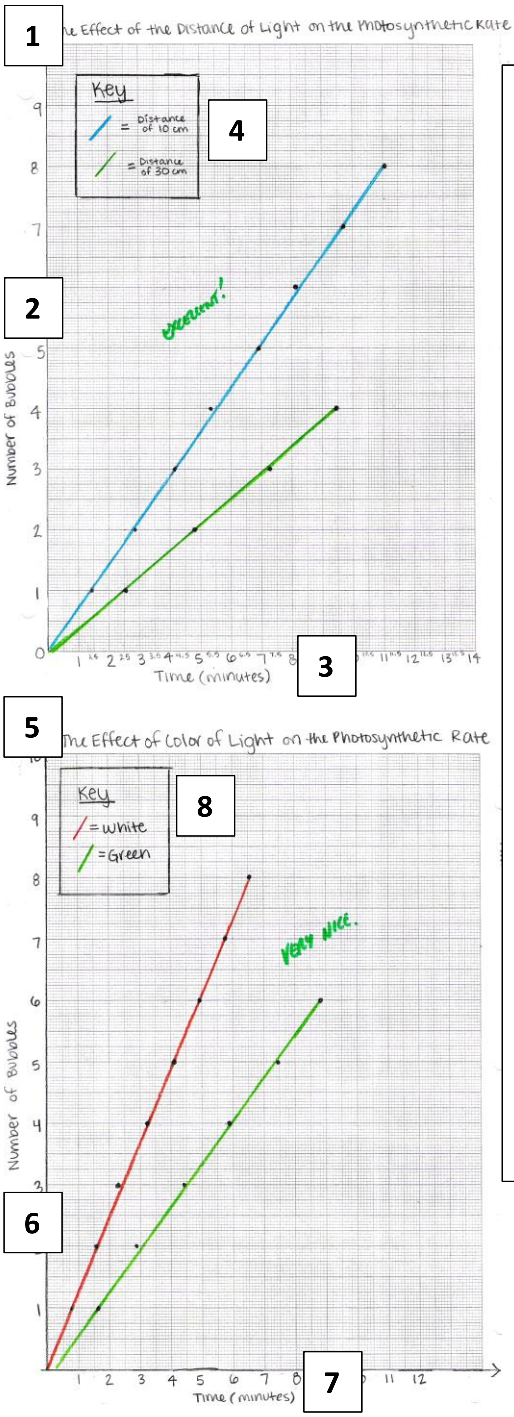


Figure Legend:

1. **Graph Title- "The Effect of Distance of Light on the Photosynthetic Rate"**
2. **Y-axis – Number of Bubble**
3. **X-axis – Time (minutes)**
4. **Graph Key – (10cm distance, 30cm distance)**
5. **Graph Title – "The Effect of Color of Light on the Photosynthetic Rate"**
6. **Y-axis – Number of Bubble**
7. **X-axis – Time (minutes)**
8. **Graph Key – (White Light, Green Light)**

proved effective. In this activity, the rate of oxygen bubble production was related to the overall rate of the photosynthetic process.

The data collection involved in this activity included recording the time it took to produce each consecutive oxygen bubble. Some students varied the aquatic plant's distance from the light source while other groups tested the color, or wavelength, of the light. This was accomplished by wrapping the entire test vessel with green, transparent cellophane.

One problem encountered was that not all of the aquatic plant samples were photosynthetically active enough to produce consistent and reliable oxygen bubbles. Thus, a few groups had to combine with each other in order for all students to collect useful data. After data were collected, groups that tested different variables shared data.

Students were instructed to graph the results of each experiment on separate graphs as illustrated in Figure 3. The quantification method resulted in a data set that required the "bubble number" to be graphed as a function of time. In each graph, two separate lines were included. In the experiment investigating light intensity, the data collected at a close distance and the data collected at a further distance were graphed as individual lines. Likewise, the same was done on the second graph, one line resulting from the white light, and one line from the green light. In this investigation the concept that the slope of a graphed line represented a rate was emphasized. Thus, students calculated and compared slope values as a component of the post-lab questions.

Investigation #4 (Photosynthesis Lab – Disk Assay) – (Appendix A)

Following Investigation #3, the second laboratory activity examining photosynthesis involved carbon dioxide as the tested variable. A large batch of 0.2% sodium bicarbonate was premixed to ease the process of material distribution. Students were randomly distributed into laboratory groups. A deviation from the illustrated laboratory apparatus (Appendix A) was the absence of a heat sink because of a lack of availability. Heat production from the incandescent light bulbs was a concern, so they were exchanged in favor of compact florescent bulbs (CFL). The writer believes that the laboratory results were reliable with this modification.

In the presence of light, oxygen production causes the spinach leaf disks to become buoyant. For quantification, students counted the number of floating disks each minute. The concept of a carbon dioxide source being critical to the photosynthetic process was verified unanimously among groups. Some groups collected very regular data with the disks floating up consistently. There were a few groups that observed more erratic results – short intervals where many disks became buoyant and other time interval during which no additional disks floated. However, in all groups the supply of carbon dioxide (from the dissolved sodium bicarbonate) resulted in more floating spinach disks compared to the samples that only included water.

Students then had to graph the number of floating disks as a function of time for each data set. This produced 2 separate lines on the graph – one for the sample that included sodium bicarbonate, and the control sample that only used tap water. As described, some groups collected data that resulted in nearly linear graphs. Other groups had more erratic data. Regardless, this activity provided the desired graphing practice, and it supported the conceptual ideas being investigated.

Investigation #5 (Respiration Rate – Yeast) – (Appendix A)

Continuing in Unit III, the concepts of aerobic cellular respiration and anaerobic fermentation were introduced. Prior to this lab investigation, a fermentation activity utilizing yeast was conducted as part of an existing “mini-lab”. Thus, students already had some background knowledge concerning the topic. In Investigation #5, a small-diameter tube connected to a rubber stopper is inserted into a test tube containing a yeast culture. The sucrose concentration provided to the yeast was varied in this experiment. A small drop of colored solution introduced into the tubing acted as an “indicator”. Carbon dioxide gas produced during fermentation forces the indicator to move through the tubing. The distance that the indicator traveled through the transparent tubing (per unit time) was used to quantify the respiratory rate.

Large beakers containing pre-mixed concentrations of sucrose were situated in a hot-water bath set at 50°C.

Figure 4: Investigation #5 Exemplar

The experiment was flawed with several problems, so the instructor provided some additional data to graph. The complex nature of the representation was intentional

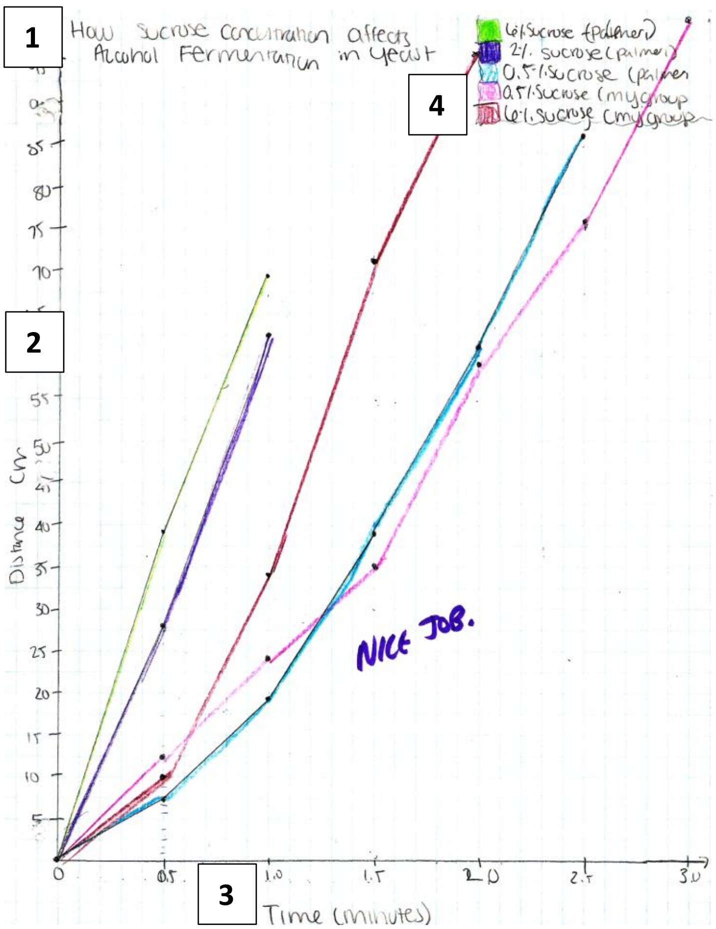


Figure Legend:

1. **Graph Title – "How Sucrose Concentration Affects Alcohol Fermentation in Yeast"**
2. **Y-axis – Distance (cm)**
3. **X-axis – Time (minutes)**
4. **Graph Key – coded for various sucrose concentrations**

Students were randomly distributed into laboratory groups for this experiment. Following the supplied laboratory procedure, students tested various concentrations of sucrose and collected data using the laboratory apparatus (see Appendix A). Some adjustments were made while this experiment was conducted. Several groups had difficulties because the carbon dioxide production was excessive, either blowing past the indicator, or moving it at a speed that impeded data collection. However, most groups were eventually able to collect usable data. The researcher introduces several modifications to the procedure that could be useful in the future. The standardized temperature of 50°C could be reduced, or the amount of yeast utilized could be less, perhaps 0.5 grams instead of 1.0 grams. These adjustments would likely reduce the rate of carbon dioxide production and facilitate data collection.

In addition to data collected by students, the instructor also supplied students with previously obtained data. Students were instructed to represent all of this quantitative information on a single graph, as illustrated in Figure 4. The distance the indicator traveled in each trial was graphed as a function of time, resulting in a graph that included multiple lines. Due to the excessive carbon dioxide production in most trials, there was not a significant distinction in the slope (rate) of each respective line. On a positive note, the nature of the graphs produced during this activity did provide much desired, intentional practice involving complex representations.

Investigation #6 (Lactic Acid Buildup) – (Appendix A)

Cellular respiration was one of the fundamental concepts covered in this unit of study. Aerobic respiration and various forms of fermentation were detailed during note taking and when engaged in certain activities, such as those experienced with Investigation #5. Thus, Investigation #6 was introduced when students already had significant background knowledge concerning the topic.

In this activity, students squeezed a tennis ball with their non-dominant hand. The total time and the number of squeezes were counted until the student's hand became fatigued. The reality of muscle fatigue is related to lactic acid build-up from the fermentation process. This activity is not entirely authentic; however, it does involve data collection and graphical representation. After collecting their data, students produced a bar graph comparing the number of squeezes among peers in the class. Also, the time elapsed before fatigue was experienced was also represented with a line graph. This activity provided students with practice constructing appropriate scales. Inevitably, one of the students in each class produced data that might be considered an “outlier”, forcing students to adjust and compensate with the design and chosen scale increment.

Investigation #7 (Enzyme Activity – Temperature and pH) – (Appendix A)

Investigation #7 was conducted immediately after the completion of Unit III, but before beginning Unit IV. Although not assessed in the previous unit, the concept of starch being broken down into sugar related closely with cellular respiration. This laboratory investigation spanned two consecutive days. The first component of the lab examined how temperature affects the activity of the enzyme amylase. On the second day, students determined how pH influences the enzyme. Prior to the lab, a large volume of buffered starch solution, an acidic iodine solution, and a stock solution of α-Amylase were prepared. The enzyme and starch solutions were placed under variable temperature treatments.

Students were randomly divided into laboratory groups for the execution of this lab. For each trial, students obtained starch and enzyme from each respective temperature treatment. 1.0 mL of the enzyme was introduced into the starch test tube, mixed, and allowed to catalyze for 1.5 minutes. At the conclusion of this time period, 10 drops of the acidic iodine was added to stop the decomposition reaction and the purple-black color that developed indicated the relative amount of starch remaining. To quantify these remaining concentrations, the contents of the test tube were poured into a six-well plate. Students proceeded to follow this same procedure for the remaining temperature treatments. Afterwards, the six-well plates were scanned and these images files were copied into each student's folder on the district's intranet.

The second day of the lab was conducted in the same manner, except pH was varied using acetate and phosphate buffered solutions and all samples were exposed to ambient temperature. Based on pre-lab experimentation, the instructor had students run each trial for two minutes. As was done before, each group prepared a six-well plate, which was scanned prior to the end of the

Figure 5: Investigation #7 Exemplar

Different variables (temperature and pH) were tested on two consecutive class periods. Students were required to reference both graphs to identify ideal conditions for the enzyme α-amylase

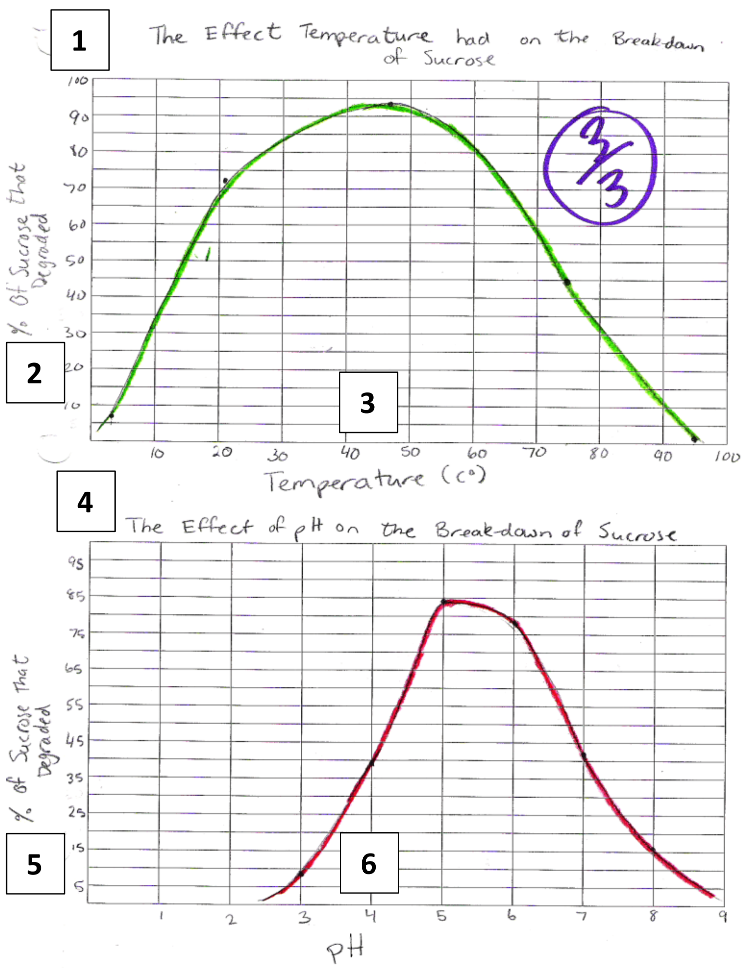


Figure Legend:

1. **Graph Title – "Effect of Temperature…"**
2. **Y-axis – % starch degraded**
3. **X-axis – Temperature (C°)**
4. **Graph Title – "Effect of pH…"**
5. **Y-axis - % starch degraded**
6. **X-axis - pH**

class period.

To quantify the concentration of starch, the scanned images of the six-well plates were analyzed using the software program Image-J. Due to complications, it was decided that quantification with Image J would be conducted as a large-group classroom activity. A few of the experimental examples were selected and quantified and average values were calculated for each respective temperature and pH value. Afterwards, students used these values to determine the remaining starch concentrations – this was accomplished via a standardized curve that the instructor had prepared.

Using the quantified results, students determined the percent of starch degraded and constructed two individual graphs – one that depicted the results of the temperature experiment, and the other which illustrated the results of the pH experiment. In each graph, the percent starch degraded was graphed as a function of the appropriate independent variable as illustrated in Figure 5.

RESULTS AND ANALYSIS

Pre-Test and Post-Test Administration

The pre-test and post-test utilized in this study was administered to all students enrolled in the microbiology classes as part of a planned curricular activity. These tests were composed of two separate and distinct parts. “Part 1” included four questions that assessed graph construction skills, point plotting, and interpretation. This portion of the test had a maximum value of 20 points and was assessed via a rubric (Appendix D). “Part 2” of the assessment consisted of 10 multiple-choice questions which incorporated supplied graphs. Answering these questions relied on the student analyzing and extracting information explicitly from the graphs. Each question was valued at 2 points, resulting in a combined worth of 20 points.

Part 1 and Part 2 of the assessment were administered on two separate but consecutive days. This decision was made because the researcher considered the significant amount of time that might be required in completing the graph construction problems encountered on Part 1 of the test. Pre-tests were administered at the beginning of the semester, before any of the related graphing investigations were introduced. As with the pre-test, post-testing was completed on two separate instructional periods – this was conducted after the relevant activities were accomplished. During the administration of these tests the researcher was unaware of which students had returned their consent forms, or which students had granted or denied consent to participate.

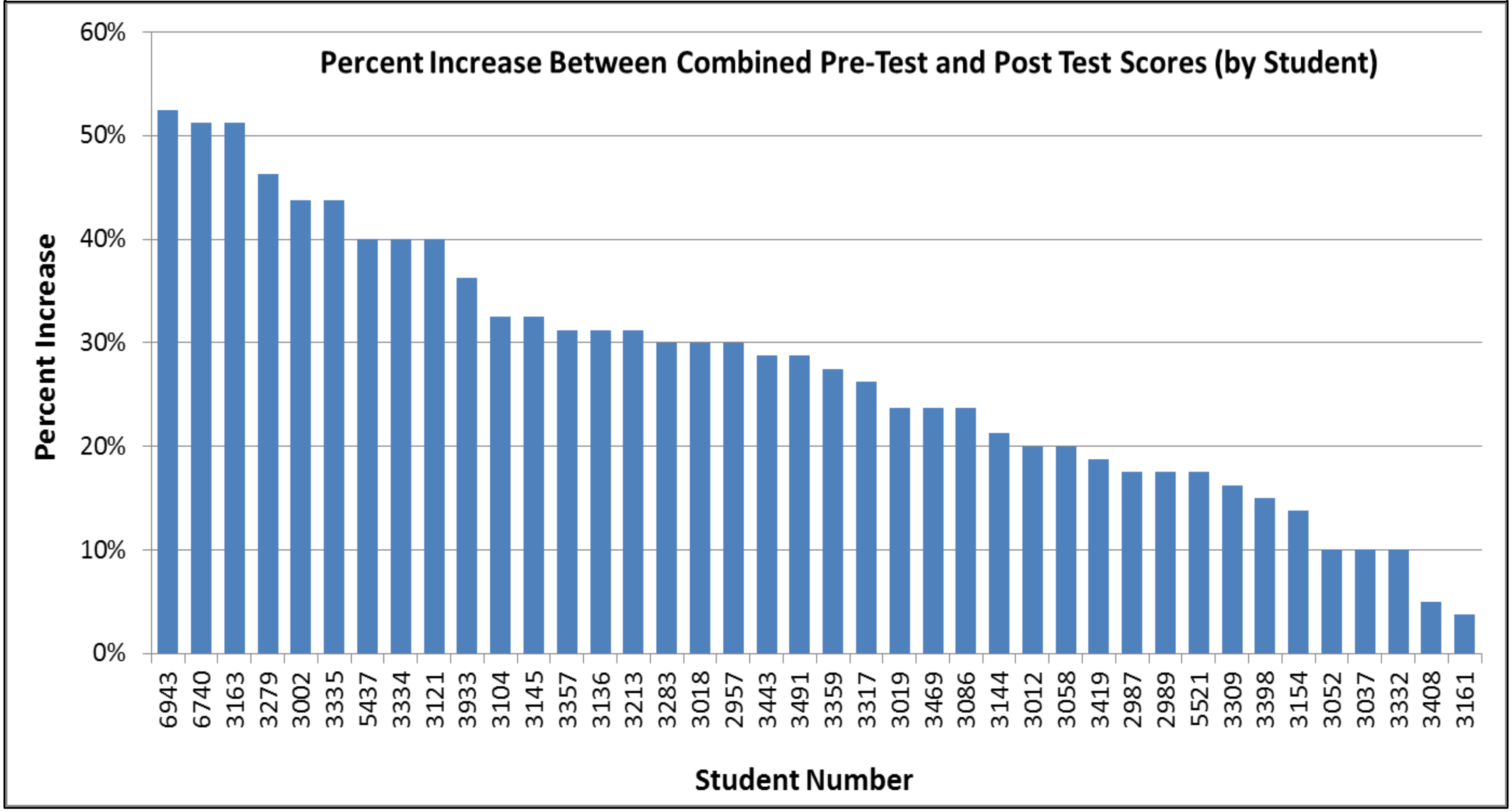
Data Analysis – Combined Pre-Test and Post-Test

Forty students consented to participate in this study, representing 85% of the students enrolled in the instructor’s two microbiology classes. Each participating student’s scores from

Part 1 and Part 2 of the pre-test were added to establish a "combined" score. The pre-test yielded an average combined score of 57.8%. The corresponding average for the post-test was determined to be 85.2%, representing a substantial improvement. All participating students achieved a combined post-test score that exceeded their pre-test score, and the average increase was calculated at 27.4%. These increases ranged between 52.5% and 3.75%. Figure 6 illustrates how much each student improved on the post-test in comparison to the pre-test. Table 2 lists each student's combined scores (as a percentage) on both tests, as well as the percent change between each. To determine whether the differences between combined pre-test and post-test scores were statistically significant, a paired t-test was performed. The paired t-test yielded a p-value of 0.000. Thus, the null hypothesis is rejected and the alternative hypothesis was accepted – there is a statistical difference between achievements when comparing pre-test and post-test scores.

Figure 6: Percent Difference Between Combined Pre-Test and Post-Test Scores

The range of improvement yielded on students' pre-test and post-test scores. All participating students demonstrated improvement when evaluating the combined scores of Part 1 and Part 2 of the assessment.



Data Analysis – Part 1 and Part 2 Pre-Test and Post-Test

Although the difference in combined scores appeared impressive, the researcher recognized that many of the students attained this improvement due to the influence of Part 1. This component tested graph construction and related skills. Thus, the decision was made to individually analyze Part 1 and Part 2 of the assessments. Regarding the pre-test, Part 1 of the assessment yielded an average of 43.9%. On the post-test, the participants' scores increased impressively to an 88.6% average. Only one student managed a post-test score less than what they achieved on the pre-test (See Table 1). Using a paired t-test, a p-value of 0.000 was obtained from the data comparison. Not surprisingly, the differences identified in Part 1 of the assessment proved to be statistically significant.

The researcher questioned whether there was truly a statistical difference between the pre-test and post-test scores that were obtained from Part 2 of the assessment. The initial pre-test of Part 2 resulted in a student average of 71.8%. On the subsequent post-test, the average climbed to 81.8%, resulting in a mean increase of 10.0%. The 40 student sample was subjected to a paired t-test, yielding a p-value of 0.001. Thus, there was indeed a statistical difference between Part 2 of the assessment's pre-test and post-test scores. Interestingly, five students did worse on the multiple choice graphical analysis questions that made up this component of the test. In addition, 12 students produced scores identical to their pre-test scores. The test scores from each component of the assessment are listed in Table 2.

Table 2: Pre-Test and Post-Test Data from all Assessment Components
All students' test scores improved when comparing the combined pre and post-test scores. One student achieved a lower post-test score on Part 1 of the test compared to the initial pre-test score. Five students did worse on Part 2 of the test and 12 students achieved grades on Part 2 of the test that were equal to their initial scores. Green shading is used to represent an increase, yellow indicates no change, and red denotes a decrease.

Stu. #	**Tests Combined**			**Graph Construction (Part 1)**			**Graph Analysis (Part 2)**		
	Pre	Post	+/-	Pre	Post	+/-	Pre	Post	+/-
2957	67.5%	97.5%	**30.0%**	45.0%	95.0%	**50.0%**	90.0%	100.0%	**10.0%**
5521	77.5%	95.0%	**17.5%**	75.0%	100.0%	**25.0%**	80.0%	90.0%	**10.0%**
2987	70.0%	87.5%	**17.5%**	70.0%	95.0%	**25.0%**	70.0%	80.0%	**10.0%**
2989	57.5%	75.0%	**17.5%**	25.0%	70.0%	**45.0%**	90.0%	80.0%	**-10.0%**
3002	43.8%	87.5%	**43.8%**	27.5%	85.0%	**57.5%**	60.0%	90.0%	**30.0%**
3019	51.3%	75.0%	**23.8%**	42.5%	80.0%	**37.5%**	60.0%	70.0%	**10.0%**
3052	68.8%	78.8%	**10.0%**	57.5%	87.5%	**30.0%**	80.0%	70.0%	**-10.0%**
3104	57.5%	90.0%	**32.5%**	35.0%	100.0%	**65.0%**	80.0%	80.0%	**0.0%**
5437	31.3%	71.3%	**40.0%**	12.5%	62.5%	**50.0%**	50.0%	80.0%	**30.0%**
3136	58.8%	90.0%	**31.3%**	37.5%	100.0%	**62.5%**	80.0%	80.0%	**0.0%**
3154	66.3%	80.0%	**13.8%**	32.5%	100.0%	**67.5%**	100.0%	60.0%	**-40.0%**
3161	46.3%	50.0%	**3.8%**	62.5%	60.0%	**-2.5%**	30.0%	40.0%	**10.0%**
3213	68.8%	100.0%	**31.3%**	77.5%	100.0%	**22.5%**	60.0%	100.0%	**40.0%**
3309	78.8%	95.0%	**16.3%**	57.5%	100.0%	**42.5%**	100.0%	90.0%	**-10.0%**
3317	61.3%	87.5%	**26.3%**	42.5%	95.0%	**52.5%**	80.0%	80.0%	**0.0%**
3357	48.8%	80.0%	**31.3%**	27.5%	90.0%	**62.5%**	70.0%	70.0%	**0.0%**
3359	70.0%	97.5%	**27.5%**	80.0%	95.0%	**15.0%**	60.0%	100.0%	**40.0%**
3398	58.8%	73.8%	**15.0%**	67.5%	87.5%	**20.0%**	50.0%	60.0%	**10.0%**
3408	95.0%	100.0%	**5.0%**	90.0%	100.0%	**10.0%**	100.0%	100.0%	**0.0%**
3012	80.0%	100.0%	**20.0%**	70.0%	100.0%	**30.0%**	90.0%	100.0%	**10.0%**
3018	36.3%	66.3%	**30.0%**	22.5%	72.5%	**50.0%**	50.0%	60.0%	**10.0%**
6740	35.0%	86.3%	**51.3%**	10.0%	92.5%	**82.5%**	60.0%	80.0%	**20.0%**
3037	87.5%	97.5%	**10.0%**	85.0%	95.0%	**10.0%**	90.0%	100.0%	**10.0%**
3058	75.0%	95.0%	**20.0%**	60.0%	100.0%	**40.0%**	90.0%	90.0%	**0.0%**
3086	73.8%	97.5%	**23.8%**	57.5%	95.0%	**37.5%**	90.0%	100.0%	**10.0%**
3933	36.3%	72.5%	**36.3%**	22.5%	95.0%	**72.5%**	50.0%	50.0%	**0.0%**
6943	45.0%	97.5%	**52.5%**	30.0%	95.0%	**65.0%**	60.0%	100.0%	**40.0%**
3121	42.5%	82.5%	**40.0%**	35.0%	85.0%	**50.0%**	50.0%	80.0%	**30.0%**

Table 2 (Cont'd)									
3144	78.8%	100.0%	**21.3%**	57.5%	100.0%	**42.5%**	100.0%	100.0%	**0.0%**
3145	60.0%	92.5%	**32.5%**	30.0%	85.0%	**55.0%**	90.0%	100.0%	**10.0%**
3163	37.5%	88.8%	**51.3%**	35.0%	87.5%	**52.5%**	40.0%	90.0%	**50.0%**
3279	28.8%	75.0%	**46.3%**	27.5%	90.0%	**62.5%**	30.0%	60.0%	**30.0%**
3283	31.3%	61.3%	**30.0%**	12.5%	62.5%	**50.0%**	50.0%	60.0%	**10.0%**
3332	65.0%	75.0%	**10.0%**	30.0%	70.0%	**40.0%**	100.0%	80.0%	**-20.0%**
3334	52.5%	92.5%	**40.0%**	35.0%	95.0%	**60.0%**	70.0%	90.0%	**20.0%**
3335	47.5%	91.3%	**43.8%**	35.0%	82.5%	**47.5%**	60.0%	100.0%	**40.0%**
3419	33.8%	52.5%	**18.8%**	17.5%	55.0%	**37.5%**	50.0%	50.0%	**0.0%**
3443	63.8%	92.5%	**28.8%**	37.5%	95.0%	**57.5%**	90.0%	90.0%	**0.0%**
3469	76.3%	100.0%	**23.8%**	52.5%	100.0%	**47.5%**	100.0%	100.0%	**0.0%**
3491	50.0%	78.8%	**28.8%**	30.0%	87.5%	**57.5%**	70.0%	70.0%	**0.0%**
Avg.	**57.8%**	**85.2%**	**27.3%**	**43.9%**	**88.6%**	**44.6%**	**71.8%**	**81.8%**	**10.0%**

Table 3: Results of Statistical Analysis of a Paired T-Test on Pre-Tests and Post-Tests
The combined tests as well as the individual components were analyzed and the corresponding p-values signify statistical significance for both Part 1 and Part 2 of the assessment

Statistical Analysis Using a Paired T-Test			
Tests Component(s)	**Null Hypothesis**	**P-Value**	**Results**
Combined (Part 1 + Part 2)	$T_{pre} = T_{post}$	0.000	Statistical Difference *(Reject Null)*
Part 1 (Graph Construction)	$T_{pre} = T_{post}$	0.000	Statistical Difference *(Reject Null)*
Part 2 (Graph Analysis)	$T_{pre} = T_{post}$	0.001	Statistical Difference *(Reject Null)*

DISCUSSION

Discussion of Data

The null hypothesis that exposure to authentic data collection and routine graphing practice would not have an effect on students' measured graphical literacy skills was not supported. Analyses from both components of the administered pre-test and post-tests proved to be statistical significant, as indicated in Table 3. Paired t-tests performed on Part 1, Part 2, and the combined test components yielded respective p-values of 0.000, 0.001, and 0.000. Based on these results, it can be assumed that embedding data collection and authentic graph construction activities into a science curriculum positively influence student proficiencies constructing, analyzing, and deciphering graphs.

The most significant and impressive gains were observed with students' graph construction skills. The first question posed the greatest challenge encountered on the graph construction component of the assessments. Given appropriate data, students had to construct a particularly difficult graph that included bivariate data, necessitating the inclusion of two separate y-axes. It is entirely possible that this was a student's first ever encounter with the construction of this style of representation. The researcher noted that several students appeared overwhelmed by the graphing task and did not know how to proceed with the organization of such a graph. The struggles on Question #1 of the assessment certainly were responsible for the low 43.9% average achieved on Part 1. This study's exposure to complex representations may have provided the necessary knowledge in dealing with multiple variables and data sets, contributing to the much-improved post-test average of 88.6%. Only one student did worse on the subsequent post-test. This individual was a special education student that is easily distracted and often has difficulty focusing. The author suspects that this student was having these particular issues during the completion of the post-test.

With regard to the graphical analysis component of the assessment, average improvements were far less than those attained on Part 1. Although a statistical difference was realized, the 10.0% average increase paled in comparison to the improvement on the graph construction element. In reflection, the author recognized that the graphical analysis questions were not developed such that they were sufficiently difficult. The average pre-test score of 71.8% was higher than the writer expected or desired. Six students actually achieved a perfect 100.0% on the pretest and an additional eight students scored 90.0%. These 14 pre-test scores represented 35% of the participating sample. Mathematically, it was impossible or unlikely for some students to demonstrate any improvement on Part 2 of the assessment due to their high initial achievement.

General Discussion

The majority of the writer's experience is teaching at the middle school level. An involuntary transfer resulted in the researcher conducting this study in an unfamiliar high school setting. Without sufficient experience teaching high school grade levels, it was unknown what level of difficulty would represent a substantial challenge to most students. Also, the possibility of being transferred back to the middle school was presented by administrators during the development of activities and during the design of pre-test and post-test assessments. As with the design of each investigative activity, the researcher considered the assessment as something that might require modification to make it more appropriate for middle school students. A combination of these influences might be responsible for the author overestimating the difficulty

Figure 7: Common Scale Issues (1)
Some students had difficulty with the establishment of an initial "0" value on the X and Y axes when graphing data from the investigations

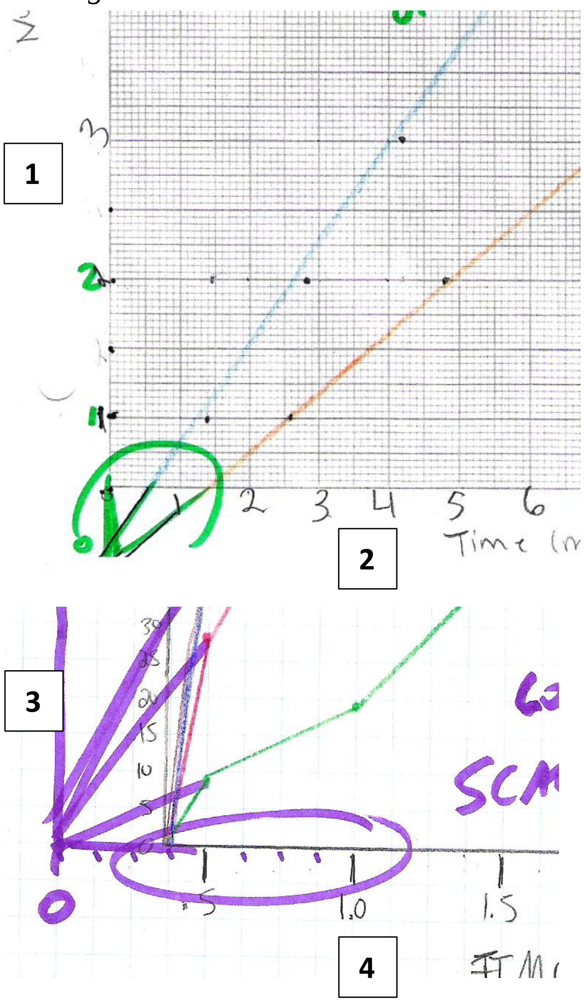


Figure Legend:

1. **X-axis – Values adjusted for corrected origin**
2. **Y-axis – Time (minutes)**
3. **Y-axis – Shifted to accommodate the provided values**
4. **X-axis – Time (minutes)**

of the graph analysis questions. If this study were repeated at the high school level, it is suggested that the difficulty of these questions be amplified such that questions mimic those presented on the ACT.

The author was impressed with the improved competency that students demonstrated with graph construction. In addition to the presented empirical statistical data, the instructor subjectively noted improvements during the course of the semester. Basic improvements included understanding the orientation of axes and variables. Students exhibited a more deliberate effort to label axes, denote units, and provide useful titles. Finally, students became more skilled at devising logical scales, utilizing space on the provided graph paper, and generally making their produced graphs more aesthetically pleasing.

Errors in scale design were noted in both the assignments and in the assessments used in this study. The researcher subjectively noted improved skill dealing with scale during the course of the study. Figure 7, Figure 8, and Figure 9 illustrate some of the common deficiencies encountered.

Figure 8: Common Scale Issues (2)

Some students had difficulty establishing and applying a consisent scale increment on the assigned graphing tasks incorporated in each investigation

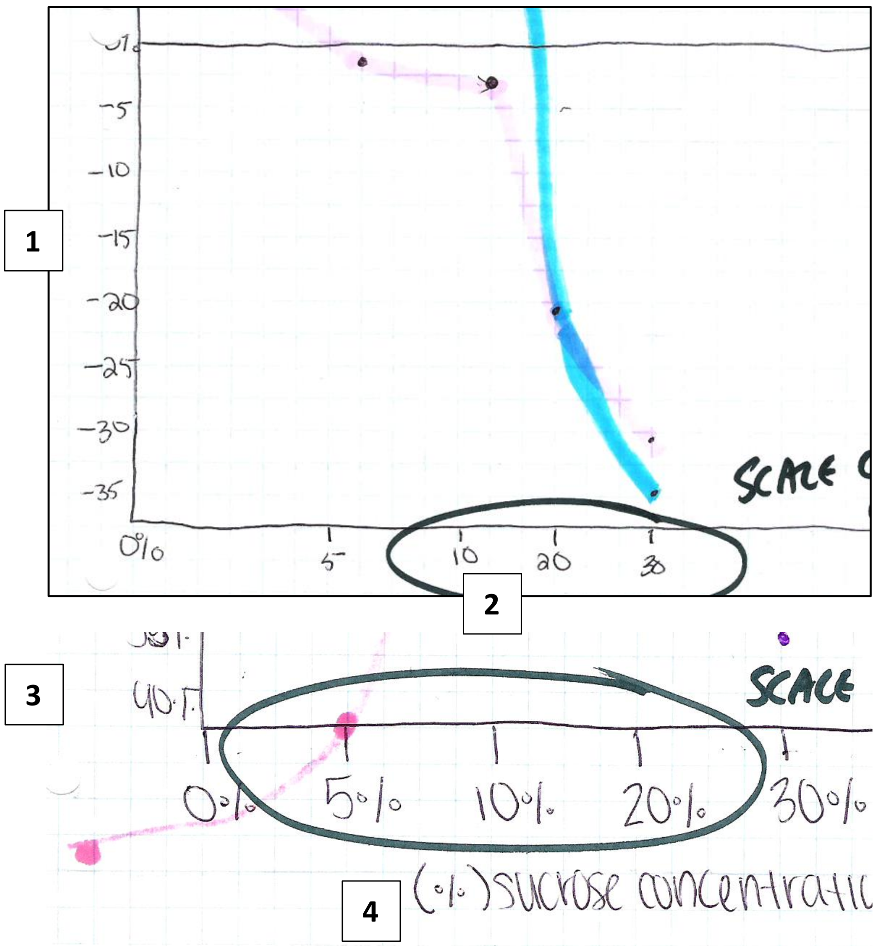


Figure Legend:

1. **Y-axis – negative % change in mass**
2. **X-axis – % sucrose concentration (not spaced proportionally)**
3. **Y-axis – negative % change in mass**
4. **X-axis – % sucrose concentration (not spaced proportionally)**

Figure 9: Scale Issues on the Pre-Test

These students peformed better than most students on Question #1 of Part 1 of the assessment. However, these examples illustrate how students have a tendency to "assign" values to lines based on the provided data points, rather than using a consistent and logical incremental value.

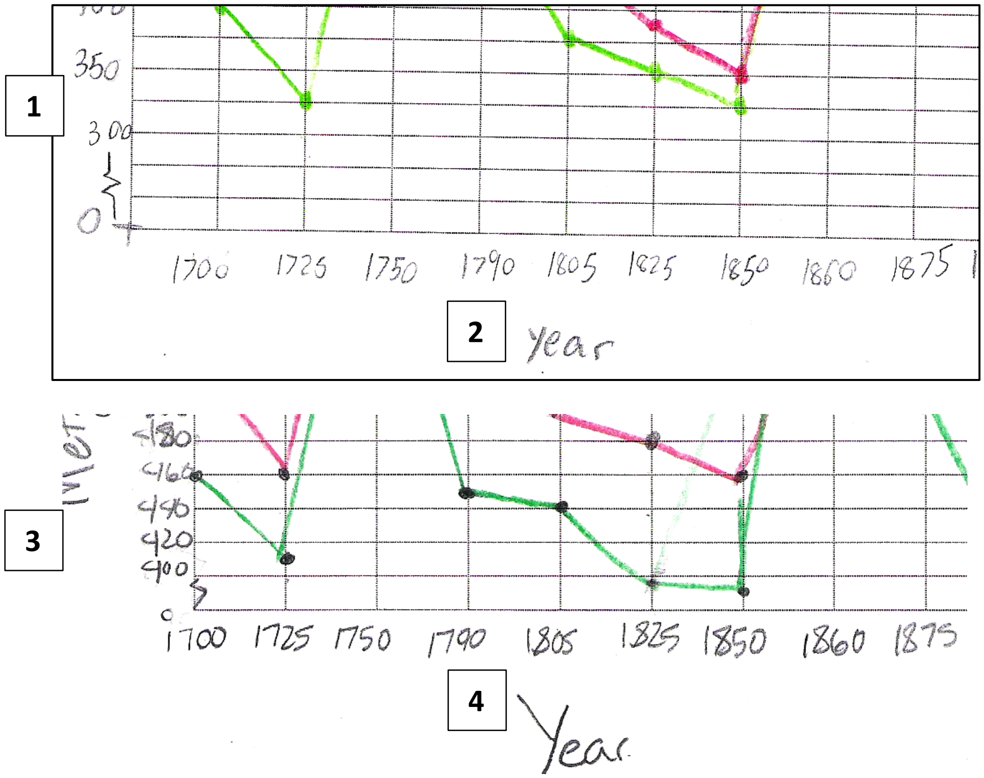


Figure Legend:

1. **Y-axis – methane concentration (ppb)**
2. **X-axis – Year – values that are not spaced incrementally**
3. **Y-axis – methane concentration (ppb)**
4. **X-axis – Year – values that are not spaced incrementally**

To aid in graph analysis, the instructor provided immediate feedback by assessing student submissions and returning them in short time periods. Having tangible, student-produced examples as a reference was a considerably effective method in teaching and evaluating graphs for information and meaning. As pointed out by Coleman and others, students cannot be

Figure 10: Graph Titling

Although students understood that titling their graph was required, many students did not provide meaningful titles that described the representation adequately. This student simply titled their graph "Respiration Lab". The author noted that the titles of graphs gradually improved during the course of this study.

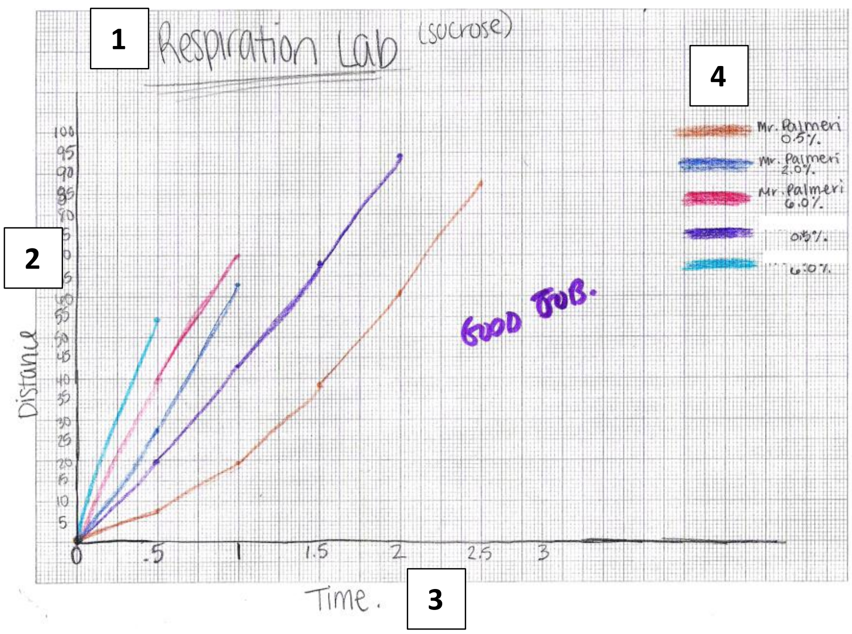


Figure Legend:

1. **Graph Title – "Respiration Lab"**
2. **Y-axis – Distance**
3. **X-axis – Time (minutes)**
4. **Graph Key – coded for various sucrose concentrations**

expected to accidently gain these skills, rather, graphing should be taught within the context of science and embedded into the curriculum (2011). Further research has supported the strategy of systematically teaching students to deal with quantitative information and graphical representation (Tairab and Khalaf Al-Naqbi, 2004). The instructor included explicit, direct instruction regarding graph construction before tasking students with the included graphing activities and such instruction was also presented after returning work to students. This provided the researcher with an opportunity to explain common mistakes and flaws that were identified when students attempted to evaluate their produced graphs. During several of the investigations utilized in this study, the concept of relating the slope of a plotted line to a functional rate was introduced and emphasized. A conceptual error that was uncovered on the post-test included responses to Question #3 on Part 1 of the assessment. Several students confused the relative amount (height graphed) with the concept of slope being equivalent to a respective rate. This phenomenon has been identified historically in elementary-aged learners and is an error that has been described as *slope-height confusion* (Shah and Hoeffner, 2002).

In several instances, severe graph construction misunderstandings required one-on-one direct tutoring to support deficient students. Confusing the orientation of the axes, erratic changes in scale increments, and the inability to accurately plot points summarizes the majority of these deficiencies.

Discussion of Investigations

Investigation #1 employing the Grow-Toys was successful and well-liked by students. The produced graph utilizing two separate y-axes was unique and corresponded to the most challenging graph construction problem on the measured assessments (Question #1 of Part 1). As graph cognition researchers have identified, scale considerations should reflect the goal of either understanding relative relationships or absolute information and students "have difficulty translating between different graphic scales." (Shah, Mayer, and Hegarty, 1999). Since the objective of this graphing activity was to compare relative changes in size and mass, the differences in scaling were justified.

The instructor will consider the possibility of conducting this activity using a guided inquiry approach. For this method to be successful, significant emphasis would have to be placed on the quantitative components that allow for the investigation to serve as an effective graphing exercise. In the arena of physics education, practitioners advocate using data collection and graphing as a means of "discovering" physical laws by recognizing mathematical relationships between variables (Oakes, 1997). Indeed, the student-produced graphs in this activity yielded a perfectly inverse relationship.

Investigation #2 involving osmosis in potato and cantaloupe produced exceptional data that lent itself to graph construction and analysis. This comprehensive laboratory investigation supplied the precise type of context that experts advocate for when attempting genuine statistical examinations (Friel, et al., 2001). The graphs that students produced were highly reliable and allowed the instructor to ask students for interpolated values. Students determined isotonic sucrose concentrations for each cell type (potato and cantaloupe). Solutions were mixed based on these student estimates and samples were soaked for 24 hours to test the validity of each isotonic prediction. To the delight of the researcher, the tested samples yielded almost no change in mass. There is tremendous value in having students utilize graphs they've produced for the purposes of interpolation and extrapolation. The researcher aims to devise more of these types of auxiliary, predictive activities with student-produced graphs. Some practitioners even promote the idea that students should predict what the general shape of their graph will look like before actually graphing the data (Connery, 2007). There is merit in this approach because it introduces another added element of predicting and testing predictions, a process that is fundamental to the scientific process.

Overall, Investigation #3 went relatively well except for a few groups which inherited *Elodea* that was uncooperative. It is unknown why some of the aquatic plant samples produced consistent oxygen and others produced very little. Fortunately, groups were combined and all students were able to obtain data. During the second semester of the school year, the author had some success “starving” the aquatic plants of light for several days prior to attempting the laboratory activity. The instructor is also investigating the possibility of utilizing dense algal cultures in glass laboratory flasks that would utilize a similar setup. Continuing with photosynthesis activities, Investigation #4 allowed for the examination of additional variables. The floating disk assay was a successful, quantitative exercise.

Investigation #5 was riddled with the most issues. The researcher believes that using fine-diameter tubing and indicator movement to quantify carbon dioxide gas production is a great concept. To make data collection and quantification more reliable, some adjustments need to be considered. Rapid carbon dioxide production resulted in excessive pressure and gas blowing past the indicator. Thus, one consideration involves using less yeast – this would result in less carbon dioxide production. Another possibility is using a lower standardized temperature, but this would require additional time for the yeast to become active from its dormant state. Obviously, within the time constraints of a typical classroom period, the availability of time would be the biggest concern. A potential adjustment with the indicator would include the use of insoluble substances such that the carbon dioxide gas cannot push past.

Investigation #7 was a laboratory activity that could be considered complex but very authentic. This investigation required en extraordinary amount of pre-lab preparation to facilitate completion in the high school setting. The timing of each trial needed to be exact and uniform addition of the enzyme with a graduated pipette was required. Some laboratory groups performed the investigation perfectly, achieving a six-well plate with a spectrum of remaining starch concentrations. A few of the groups made procedural errors that affected the data collected.

Because of technical issues, the possibility of individually analyzing and quantifying laboratory results was abandoned. Thus, in a whole-group classroom setting, the instructor used three or four of the most visually acceptable six-well plate images, analyzed them via Image J, and averaged the results from each trial. Students used the collective Image J values, in conjunction with a provided standardized curve, to quantify the remaining starch concentrations. In hindsight, this may be a better method when dealing with quantifying the lab results. The nature of this investigation makes it very likely for some students to derive flawed data and the subsequently graphed results would certainly not supported conceptual understanding of the concept investigated.

Investigation #7 was unique in that graphs produced represented the comparative results of two separate experiments. The skill of associating two separate graphs certainly could be helpful for students, particularly since tests like the ACT routinely require such processing. In one study, Smith and Gentner (2011) determined that comparing contrasting examples promoted the understanding of graphical representations. The author expects that more experiences with graph comparison should be provided. For example, in a structured activity, students from dissimilar laboratory groups could evaluate each other's graphs and evaluate whether or not similar results (and conclusions) were achieved.

Limitations and Considerations for the Future

These investigations and graphing exercises reported here will definitely be utilized in the future. Some adjustments are required; however, the goal of providing realistic, authentic laboratory investigations that require data collection and the intentional practicing of complex graph construction and graph analysis was accomplished. In fact, the writer believes that additional data and graphing enrichment should be incorporated into the curriculum. The school year surrounding this study was the first year the instructor taught this microbiology course. Aside from the newly introduced investigations contained within this study, there was only one existing activity that provided any exposure or practice with graphical representations.

While requiring considerable effort, more investigations that correspond to other relevant scientific concepts should be developed and made available to practitioners. The lack of existing, authentic data-driven investigations that incorporate graphing in the microbiology curriculum of the writer's high school is, perhaps, not entirely unusual. Some researchers believe that new teachers entering the teaching profession are not qualified to provide such authentic experiences. Bowen and Roth (2005) for example, studied pre-service teacher's ability, given various scenarios, to develop appropriately designed quantitative investigations. They concluded that, "pre-service teachers need more experience in engaging in data and graph interpretation practices originating in activities that provide the degree of variation in and complexity of data present in realistic investigations" and "despite considerable preparation, and for many, despite bachelor of science degrees, pre-service teachers do not enact the (''authentic'') practices that scientists routinely do when asked to interpret data or graphs."

The conclusions of Bowen and Roth perhaps should not be generalized. However, this insight presents some unfortunate realities that exist. True, it is possible that some teachers lack the necessary knowledge and understanding to implement authentic data collection and data representation activities. Instead of dwelling on this deficiency, appropriate interventions should be conducted. The development of these types of activities involves intensive time commitments. Furthermore, logistical considerations are the tail that wags the dog when a teacher is expected to introduce "authentic" laboratory investigations in class sizes in upwards of 30 students. In the collaborative atmosphere of education, well-designed quantitative investigations should be shared amongst colleagues. Teacher preparation programs, outreach coordinators, university affiliates, and district curriculum designers should also understand the value in data-driven investigations and graphing exercises based on authentic data. The availability of curricular resources would certainly help classroom teachers to address the need for quantitative laboratory examinations.

One noticeable element missing from this study is the incorporation of computer-assisted graphing instruction and graphical representations generated via software programs. Regarding computer-assisted graphing instruction, there is some contradiction in the available literature. In one study, two different hands-on, instructional modules were used to teach two groups of students – one that included computer applications and another that did not (Ates and Stevens, 2003). It was determined that there was not any significant difference in measured graphing comprehension; both treatments were equally effective. Conversely, other research has determined that microcomputer-based laboratories (MBLs) are effective in teaching students graph comprehension relative to kinematic concepts encountered in physics classrooms (Brasell and Rowe, 1993). Of course, one benefit of introducing technology is that it can incite interest from students and engage them to a greater extent. The author considered having students produce some of the incorporated data representations with Microsoft® Excel graphs. Some researchers, however, warn that computer graphing programs allow students to "demonstrate a lack of understanding of the relationships among the graph, the type of data, the purpose of analysis, and the judgment task" (Friel et al., 2001). In the writer's experience, sometimes the immediate data organization and representation offered by computer programs produces a graph without requiring the student to consciously decide axes and orientation. For this reason, and for the sake of consistency among the incorporated investigations, computer-aided graphing was not utilized.

Another potential criticism surrounding this study is the contextual considerations. It might be argued that the improved proficiencies on the assessment were the result of students' enhanced knowledge of the corresponding content, rather than greater skill, aptitude, and familiarity with data representation. Indeed, many of the questions contained within the pre and post-test involved concepts that were investigated as part of the existing, planned microbiology curriculum. Conceptual understanding of photosynthesis, for example, would occur without the inclusion of the graphing activities incorporated by this study. Thus, there is a possibility that improved performances could be attributed to this generally attained knowledge. However, the assessments also included questions involving unfamiliar concepts that were not directly investigated. One suggested solution to this dilemma is to devise an assessment that is entirely composed of graphing analysis questions that do not correspond with topics that have been taught. In this way it would be possible to determine if students are truly able to apply their knowledge of data representation to new scenarios to which they are unaccustomed.

The author has been transferred back to the district's middle school for the upcoming school year. Thus, translating these activities so that they are useful with younger learners is a challenge. Based on prior experience, the writer believes that seventh grade students are, in general, capable of completing similar types of graphing tasks. Researchers in the field of graph comprehension have debated whether proficiency with graphs is a matter of cognitive ability or practice. Those that insist on the cognitive considerations reference evidence of improved capabilities as a learner transition from the middle to high school ages (as cited in Friel et al., 2001). However, the instructor choses to adopt the former approach and is confident that routine, meaningful and authentic practice with graphs are necessary in the development of corresponding skills, regardless of age. Obviously the ultimate proficiency of an average seventh grade student cannot be compared to that of a high school senior. The considerations of intellectual capability are understood, but this educator seeks to develop learners' skills to the maximum extent, regardless of what the individual's supposed cognitive ceiling might be.

CONCLUSION

The employed measurement tools indicate that exposure to authentic data collection and routine graphing practice positively supports students' graph construction and graph evaluation skills. Analyses from Part 1 and Part 2 of the administered pre-test and post-test proved to be statistically significant. Students achieved the greatest gains in the graph construction skills assessed on Part 1 of the assessment. The added, subjective observations of the author also identified improved competency organizing and representing data in graphs. The less-than desired difficulty and subsequent high achievement on Part 2 of the pre-test mathematically limited how much improvement could be demonstrated on the subsequent post-test. This study validates the importance of graph construction and analysis practice and the author expects that greater gains in achievement would have occurred with a more rigorous assessment. It is probable that the skills developed during this study will be useful in the future, when the participating students encounter new, unfamiliar representations. Ideally, the exposure received during the completion of these investigations will provide confidence to the learner when handling data and it will allow them to logically organize and construct an appropriate representation that communicates quantitative information in the same way that a scientist would. Likewise, when facing an extraordinarily complex representation, the author is optimistic that students will not be overwhelmed or frustrated. Rather, they might draw from the constructive experiences included from this study and analytically "deconstruct" and decipher graphs using the appropriately gained skills.

APPENDICES

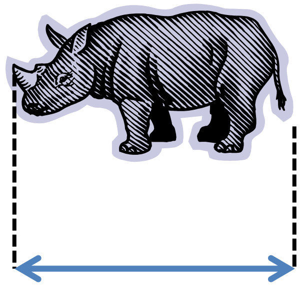
APPENDIX A:

LABORATORY INVESTIGATIONS AND ACTIVITIES

Name:____ Date: _____________ Hour: _____

"Grow Toy" Lab Investigation

Figure 11: Grow Toy Measurement



Measured length (cm)

Exercising the Scientific Method

Description of the Problem:

While browsing the aisles at a local retail store, you stumble upon various "grow toys". The product manufactures' claim that these creatures are capable of growing to 600% of their original size when placed in water. However, you are curious if this 600% is regarding the toy's length, or perhaps mass. In addition, you have heard that the maximum growth size can be affected by the amount of dissolved substances in the local municipal water supplies.

Question:

How does the concentration of dissolved salt in water affect the growth of "grow toys?"

Hypothesis:

____

Materials:

- Distilled Water
- Salt (NaCl)
- Plastic containers
- Tape
- Markers
- Stirring rod
- Electronic scale
- Metric ruler
- Beaker (1000mL)

Procedure:

Note: For 0%, use pure distilled water. Tap water can be used for the other mixtures

1) Prepare various concentrations of salt water specified in the table.
2) Measure out the appropriate amount of salt, pour the salt into the beaker, and add tap water to the 500 mL mark. Thoroughly mix until the salt has dissolved.
3) Pour the salt water into one of the plastic containers. Label the container, identifying the salt concentration and your group members.

Table 4: Salt Mixtures

% Salt Conc. *(m/v)*	Amount of Salt (g) in 500mL H_2O
0%	0.0g
2.5%	12.5
5.0%	25.0
7.5%	37.5
10.0%	50.0
15.0%	75.0

4) Carefully rinse the beaker before preparing the next salt water mixture.
5) Measure the initial mass of one of the "grow" toys. Record this value in the provided data table for 0% salt concentration.
6) Measure the initial length (see diagram) and record.
7) Place the measured grow toy in the 0% container (pure distilled water).
8) Repeat steps 5 through 7. Measure and place "grow" toys into the 2.5%, 5.0%, 7.5%, 10.0%, and 15.0% salt solutions. **Make careful measurements and ensure that the correct toy is placed in each respective container.**
9) After 24 hours (or 48 hours): Remove each grow toy from the soaking container. Gently pat-dry.
10) Measure and record the length and mass of each grow toy.
11) Calculate the percent change in mass and percent change in length for each grow toy.

Data:

Table 5: Grow Toy Mass Data

Change in Mass of "Grow Toy"			
Salt Conc. (%)	Initial Mass (g)	Mass @ 24hrs. (g)	% Change ±
0 %			
2.5 %			
5.0 %			
7.5 %			
10.0 %			
15.0 %			

Use the following formula to calculate the % Change in Mass:

$$\frac{((Mass@24hrs.)-(Initial\ \ Mass))}{Initial\ \ Mass}$$

Table 6: Grow Toy Length Data

Change in Length of "Grow Toy"			
Salt Conc. (%)	Initial Length (cm)	Length @ 24hrs. (cm)	% Change ±
0 %			
2.5 %			
5.0 %			
7.5 %			
10.0 %			
15.0 %			

Use the following formula to calculate the % Change in Length:

$$\frac{((Length@24hrs.)-(Initial\ \ Length))}{Initial\ \ Length}$$

<u>Post-Experiment Questions</u>: (Preliminary Analysis)

1) What parameter showed the greatest change? Mass or length?

2) Are these “grow toys” capable of growing up to 600% or their original size (as advertised)? EXPLAIN!

3) Imagine the manufacture wants you to clarify to growth claims in order to avoid a false-advertising lawsuit. What should the toy’s packaging claim as far as the growth potential? (Be specific).

<u>Analyze</u>:

Represent the data collected in the experiment by graphing. You will graph both the change in mass and change in length on the same graph! Separate Y-axes are required.

Conclusions: (By analyzing your graph, summarize what you found out. Accept or Reject your hypothesis)

____

____

____

____

____

____

____

Name: ____ Date: ___________ Hour:

Osmosis in Potato and Cantaloupe

Figure 12: Potato

Figure 13: Cantaloupe

Determining the Osmolarity of Various Plant Cells

Introduction:

As you have already learned, **osmosis** is the movement of water (solvent) across a selectively permeable membrane (such as the cell membrane). Although water molecules can move in and out of a cell, many dissolved solutes cannot freely diffuse across the cell membrane. These sugar and starch molecules are "trapped" within the boundaries of the cell. During osmosis, water always moves from an area of low solute concentration to an area of high solute concentration. If the solute concentration is high, then the water (solvent) concentration is low. Alternatively, if the solute concentration is low, then the water concentration is high. Remember the following tonicity designations:

- *Hypertonic: The solution has a higher solute concentration than the inner cell*
- *Hypotonic: The solution has a lower solute concentration than the inner cell*
- *Isotonic: The solute concentration inside the cell and in the surrounding solution is equal*

Osmolarity is the measure of solute concentration. In the cytoplasm of a cell there can be a variety of different dissolved solutes, such as starches, sugars, or salts. In today's laboratory our goal is to determine the solute concentration inside of potato and cantaloupe cells. To accomplish this, we will soak potato and cantaloupe in various concentrations of sucrose for 24 hours. The observed gain (or loss) in mass will allow us to estimate each respective cell's osmolarity.

Predictions:

1. Which of the two cell types do you think will have a higher solute concentration?

2. Estimate the solute concentration (in percent) of each:

   - Potato ______%
   - Cantaloupe ______%

Procedure:

1. Prepare 5 different cups (about 200mL) with the following sucrose concentrations (*m/v* - mass sucrose / volume water):

- *0% (distilled water)*
- *5% sucrose*
- *10% sucrose*
- *20% sucrose*
- *30% sucrose*

2. Using the provided cork-borer, punch out 5 equally sized sections of potato and 5 equally sized sections of cantaloupe. Cut each so they are equal in length (about 6 cm long).
3. Gently pat-dry each potato and cantaloupe cylinder.
4. Use a digital scale, measure and record the mass of each cylinder and place them in the appropriate sucrose container. **Be careful they don't get mixed up!!!**
5. Wait 24 hours: carefully remove, dry and measure the mass of each cylinder. Record the data.

Data:

Table 7: Potato Mass Data

Potato			
Sucrose Conc. (%)	Initial Mass (g)	Mass @ 24hrs. (g)	% Change ±
0 %			
5 %			
10 %			
20 %			
30 %			

Table 8: Cantaloupe Mass Data

Cantaloupe			
Sucrose Conc. (%)	Initial Mass (g)	Mass @ 24hrs. (g)	% Change ±
0 %			
5 %			
10 %			
20 %			
30 %			

Use the following formula to calculate the % Change in mass:

$$\%\ Change = \frac{((Mass@24hrs.) - (Initial\ \ Mass))}{Initial\ \ Mass} \times 100$$

Post-Lab Graphing:

Graph the % change in mass for both the potato and cantaloupe. The graph should be a 2-line, line graph that has both a positive and negative Y-axis. Color-code each line, label the axes appropriately, and include a title.

Post-Lab Questions:

1. Looking at the graph you produced, what is the approximate solute concentration in the potato and cantaloupe cells?

- Potato - _______%
- Cantaloupe - _______%

2. Which plant gained the most mass (%) in distilled water (0% sucrose)? What does this tell you about the relative solute concentrations inside each? (compare)

3. Is it possible for a specific sucrose concentration to be hypertonic to potato, but hypotonic to cantaloupe? (Look at your graph!)

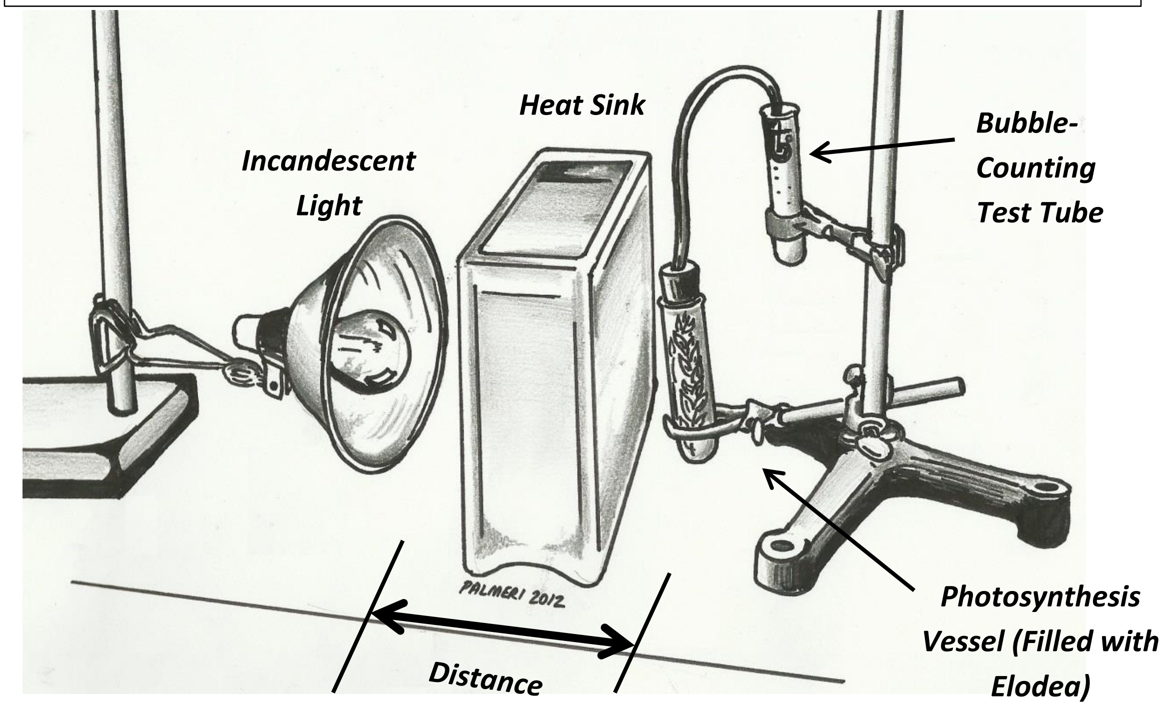
4. Name a specific sucrose concentration in which one of these cell types would gain mass and the other would lose mass. **Explain why this is so!**

Name: ____ Date: _____________ Hour: _______

Photosynthesis Lab

Aquatic Plants' Response to Various Gradients and Wavelengths of Photosynthetically Active Radiation

Figure 14: Photosynthesis Lab Apparatus Illustration



Background:

The process of photosynthesis requires electromagnetic energy to convert low-energy molecules, carbon dioxide and water, into the simple sugar glucose, an energy-rich molecule. During photosynthesis, oxygen gas is also produced (to the delight of aerobic organisms☺). The chemical equation that describes photosynthesis is written below:

$$6CO_2 + 6H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6O_2$$

Purpose:

1. To determine how light intensity affects the rate of photosynthesis.
2. To determine how the wavelength of light affects the rate of photosynthesis.

Laboratory Apparatus:

A 150W incandescent bulb will provide a continuous source of intense light. A large test-tube will be filled with the aquatic plant *Elodea*. An air-tight rubber stopper (with hole) attached to a small-diameter tube will provide the means to collect oxygen gas produced via photosynthesis. With the end of the tube immersed into a second test-tube, counting oxygen bubbles provides a useful method of quantifying the rate of photosynthesis. The distance of the light source to the *Elodea* can be varied to change the intensity of the electromagnetic radiation. To test different wavelengths of light, the test tube filled with *Elodea* may be surrounded with various light filters or wrapped with different colors of cellophane.

Question: How does distance from the light (light intensity) affect the photosynthetic rate?

Procedure – Experiment #1:

1. Mix a large quantity 2% sodium bicarbonate solution (this should already be completed).
2. Place equal amounts of *Elodea* into two large test tubes. Fill each test tube with the sodium bicarbonate solution.
3. Wrap one of the *Elodea* test tubes with 2 layers of aluminum foil to establish an experimental control. Light does not penetrate the foil!
4. Situate both test tubes at equal distances from the light source (15cm). Insert the rubber stopper and tube apparatus into each test tube.
5. Insert the end of the air tubing into a separate test tube that is **elevated above** the Elodea containers.
6. Turn on the light source. Wait 5 minutes before collecting data.
7. Once a bubble is released, start the stopwatch. Record the time each bubble releases. (Does this for 8 minutes or until 8 bubbles have been released – whichever occurs first).
8. Move the test tubes until they are 25 cm away from the light source. **Wait 5 minutes!** Repeat step #7.
9. Move the test tubes until they are 35 cm away from the light source. **Wait 5 minutes!** Repeat step #7.

Question: How does the wavelength of light (Color) affect the photosynthetic rate?

Procedure – Experiment #2:

1. Mix a large quantity 2% sodium bicarbonate solution (this should already be completed).
2. Place multiple sprigs of *Elodea* into a large test tube.
3. Fill the test tube with the sodium bicarbonate solution.
4. Wrap the test tube containing *Elodea* with clear cellophane and place it at a distance 15 cm from the light source. Insert the rubber stopper and tube apparatus into the test tube.
5. Insert the end of the air tubing into a separate test tube that is **elevated above** the Elodea vessel.
6. Turn on the light source. Wait 5 minutes before collecting data.

7. Once a bubble is released, start the stopwatch. Record the time each bubble releases. (Does this for 8 minutes or until 8 bubbles have been released – whichever occurs first).
8. Wrap the *Elodea* vessel with red, green, or blue cellophane. **Wait 5 minutes**! Repeat step #7.
9. Test as many different colors that time will allow.

Table 9: Experiment 1 Data – Distance from Light

Distance from Light (cm)	Time for Bubble to Form and Release (minutes)								
	0	1st Bubble	2nd Bubble	3rd Bubble	4th Bubble	5th Bubble	6th Bubble	7th Bubble	8th Bubble
15 cm	*0*								
25 cm	*0*								
35 cm	*0*								

Table 10: Experiment 2 Data – Color of Light

Color of Light	Time for Bubble to Form and Release (minutes)								
	0	1st Bubble	2nd Bubble	3rd Bubble	4th Bubble	5th Bubble	6th Bubble	7th Bubble	8th Bubble
White (no cellophane)	*0*								
	0								
	0								

Post-Lab Graphing:

1. Graph the results of each experiment. Be sure to use the correct style of graph. Include a graph title and label each axis.

Post-Lab Questions:

1. Identify the independent and dependent variables in the **1st experiment**?
   - Independent Variable: ________________________________
   - Dependent Variable: ________________________________
2. Identify the independent and dependent variables in the **2nd experiment**?
   - Independent Variable: ________________________________

- Dependent Variable: ______________________________

3. Looking at your graph, explain the trend witnessed during the first experiment – How does distance from the light source affect the rate of photosynthesis?
4. A classmate of yours predicted that if you double the distance, then the photosynthetic rate would be cut in half. Based on your data, do you agree with this reasoning?

5. (2nd Experiment) How did the cellophane color affect the photosynthetic rate?

6. (2nd Experiment) Which color do you predict would result in the lowest photosynthetic rate? EXPLAIN!

7. Imagine that a strand of Elodea produces 210 molecules of glucose in 8 minutes. How many oxygen molecules must have been produced during this time?

8. Calculate the slope value of each line graphed in the 1st experiment:

   - Slope 15cm: _________
   - Slope 25cm: _________
   - Slope 35cm: _________

9. Compare the slope values you calculated in question 8. This is the photosynthetic rate! How does the photosynthetic rate at 15cm compare to the rate at 35cm?

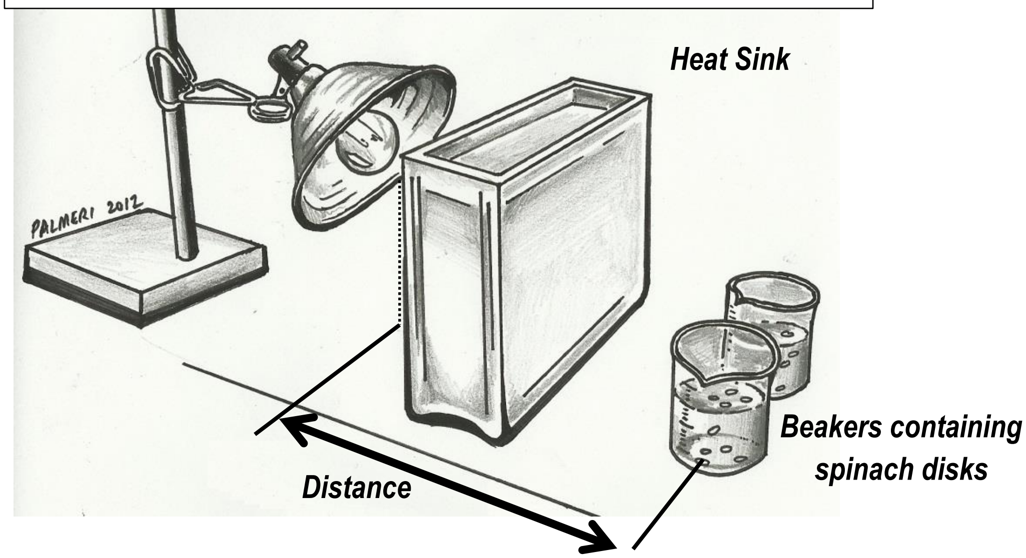
10. 100 molecules of glucose were produced in a certain amount of time when 35 cm from the light source. Predict how many glucose molecules would have been produced in the same amount of time IF the Elodea was as distance of 15 cm from the light source.

Name: ____ Date: _____________ Hour: _____

Photosynthesis Lab – Floating Spinach Disks

Assessing photosynthetic activities with a leaf disk assay

Figure 15: Floating Disk Assay Apparatus Illustration



Background:

The process of photosynthesis converts carbon dioxide gas and water into the simple sugar glucose and oxygen gas. Chemically, this is represented in the equation below:

$$6CO_2 + 6H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6O_2$$

Purpose:

To investigate how different variables affect the photosynthetic process.

Laboratory Apparatus:

Spinach disks will be subjected to a vacuum, thereby expelling all gasses in the leaf tissue – this will cause the spinach disks to sink when placed in the beakers containing water. A 150W incandescent light with shine through a glass, water-filled heat sink. Oxygen production and accumulation in the leaf tissues (due to photosynthesis) will make the leaf disks buoyant again, causing them to eventually float to the surface. The time required for disks to float allows for scientific measurement.

Question: How does CO_2 concentration affect the rate of Photosynthesis?

Procedure:

1. Mix a solution of 0.2% (w/v) sodium bicarbonate. (Pre-lab)
2. Prepare 3 beakers: **2** with 250 mL of 0.2% sodium bicarbonate and **1** with 250 mL of fresh water.
3. Cut out about 100 disks from the spinach leaves – avoid the veins!
4. Place approximately 30 disks into a 60 mL syringe filled with 0.2% sodium bicarbonate solution (you may "borrow" this amount from your beakers).
5. Evacuate all air from the syringe, cap the end, and pull to evacuate all air from the spinach disks. Hold the syringe at a vacuum for about 15 seconds.
6. Release the syringe – all disks should sink to the bottom of the syringe. Repeat step 5 if needed.
7. Remove the spinach disks and place 20 disks into the appropriate beaker
8. Rinse the syringe. Place the beaker containing leaf disks into a dark area.
9. Repeat the procedure such that you have 2 beakers of 0.2% sodium bicarbonate each with 20 spinach disks and 1 beaker with pure water containing 20 spinach disks.
10. Cover one of the 0.2% beakers with aluminum foil to block out all light. This will serve as a control.
11. Situate the uncovered 0.2% bicarbonate beaker and the pure-water beaker an equal distance of 20cm away from the light source.
12. Turn on the light and start your stopwatch.
13. Record the number of disks floating every minute in the data table below:

Data Collection – Experiment #1:

Table 11: Sodium Bicarbonate Data

0.2% Sodium Bicarbonate Solution		
Time (min)	# of Disks Floating	Percentage Floating (%)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Table 12: Pure Water Data

Pure Water		
Time (min)	# of Disks Floating	Percentage Floating (%)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Question:

Check the beaker that was covered. How many disks floated to the top when light was not available for photosynthesis?

Post-Lab Graphing:

Graph the results of this experiment on the attached sheet. Be sure to label each axis and indicate the appropriate units. Provide a title and a key. This should be a 2-line line graph!

Post-Lab Questions:

1. What are the independent and dependent variables in this experiment?
    - Independent Variable: ______________________________
    - Dependent Variable: ______________________________

2. Why did we cover up one of the beakers in this experiment?

3. Based on the results of this experiment, what conclusions can you make?

4. What is needed for photosynthesis to occur?

5. How many carbon dioxide molecules and how many water molecules are needed to produce one glucose molecule during photosynthesis?

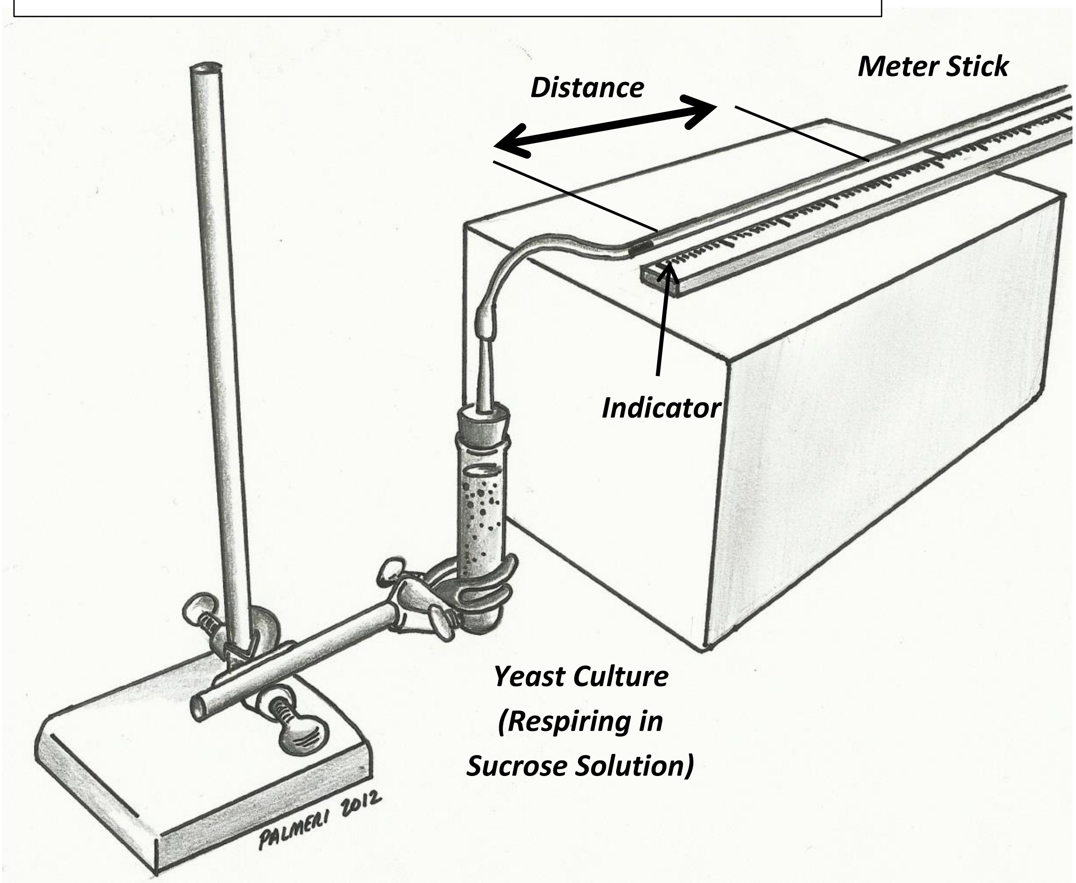
6. What are the products of photosynthesis?

Name: ____ Date: _____________ Hour: _____

Respiration Lab

The conversion of sugar to cellular energy (ATP) by fungal organisms (yeast)

Figure 16: Respiration Lab Apparatus Illustration



Background:

Yeasts are eukaryotic organisms that belong to the Fungi Kingdom. Many yeast, like the specie we are experimenting with today, are capable of both aerobic respiration (with oxygen) and fermentation (without oxygen). During respiration and fermentation, sugars are metabolized and broken down to release the energy stored in the chemical bonds of the sugar molecules. During aerobic respiration, water and carbon dioxide are produced. There are several different pathways of anaerobic respiration, one of which is fermentation. During fermentation, ethanol and carbon dioxide are produced.

Purpose:

1. To discover how the available concentration of sugar affects the respiration rate of yeast cells.

2. *Possible learning extension – Determining how temperature affects the respiration of yeast cells.*

Laboratory Apparatus:

In this lab, small-diameter tube will be connected to a rubber stopper that is inserted into a test tube containing a yeast culture. The sucrose concentration will be varied in this experiment. A small drop of indicator solution will be introduced into the tubing. Carbon dioxide gas produced during respiration will force the indicator to move through the tubing. The distance that the indicator travels down the transparent tubing (per unit time) can be used to quantify the respiratory rate.

Question: How does the sugar concentration affect the respiratory rate of yeast cells?

Procedure:

1. Mix 4%, 2%, 1%, and 0.5% sucrose solutions. (These should already be available when you arrive to class)
2. Fill the test tube approximately half way with 4% sucrose solution.
3. Add 1.0g of yeast to the culture test tube and mix rapidly with a straw.
4. Add additional 4% sucrose solution up to the line marked on the test tube.
5. Start your stopwatch. At 5 minutes insert the rubber stopper.
6. Gently add a small amount of indicator solution into the transparent plastic tubing.
7. At 7 minutes stop and reset your stopwatch.
8. Attach the tubing to the rubber stopper.
9. Start the stopwatch when the indicator reaches the “0 cm” mark on the meter stick.
10. Record the distance the indicator travels every 30 seconds, for 3 minutes, or until it has traveled 50cm.
11. Repeat steps 2 through 10 except with the 2%, 1%, and 0.5% sucrose solutions.

Table 13: Fermentation Rate Data

% Sucrose Concentration *(m/v)*	Distance Indicator Traveled @ Time (minutes)						
	0.0 min	0.5 min	1.0 min	1.5 min	2.0 min	2.5 min	3.0 min
0.5%	*0*						
1.0%	*0*						
2.0%	*0*						
4.0%	*0*						

Post-Lab Graphing:

Graph the results of this experiment. Be sure to use the correct style of graph. Include a graph title and label each axis.

Post-Lab Questions:

1. What are the independent and dependent variables in this experiment?

   - Independent Variable: ____________________________
   - Dependent Variable: ____________________________

2. What gas is being produced during the process of respiration? (what pushed the indicator through the clear tubing?)

3. Describe the results of this experiment. Make a declarative statement that answers the question being investigated.

4. Why do you think that the respiration rate might slow down if we were to continue this experiment for a long period of time?

5. Which sugar concentration yielded the greatest rate of respiration?

6. What are some potential errors in this experiment?

7. What are other variables that could be testing using this laboratory setup?

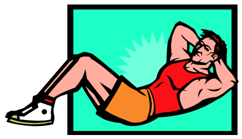
8. Describe the graph that you produced. Be specific!

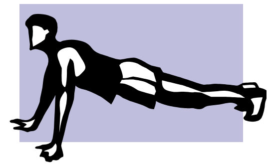
Name: ____ Date: _____________ Hour: _____

Figure 17: Exercise 1

Lactic Acid Activity

Figure 18: Exercise 2





Background:

Lactic acid in muscle that causes pain and soreness is the result of lactic acid fermentation, a process that occurs when muscles are overused. As athletes build up their strength and endurance, they don't experience lactic acid build up often. When a person uses muscles they have not used in a while, or have not conditioned to work in a specific way, lactic acid can build up as a byproduct of anaerobic metabolism. This means the body is trying to obtain ATP to give energy to the muscles, but it does not receive oxygen fast enough to support the breakdown of sugar in the presence of oxygen. So, the body does the next best thing and still obtains ATP, but does so without the presence of oxygen. This method is not as efficient and does not generate a lot of ATP, but it does generate some. The byproduct of this method can be lactic acid build up in muscle tissues.

Materials:

1 tennis ball
1 stopwatch
1 partner
1 non-dominant hand

Hypothesis:

After reading the background information, predict how many times you will be able to squeeze a tennis ball with your non-dominant hand (the one you DON'T write with) before you just can't squeeze any more.

____

____

Procedure:

1. Using the hand you don't write with, squeeze a tennis ball as fast as you can and as many times as you can until you just can't squeeze any more. Be sure to also time yourself.
2. Write the number of squeezes in the data table.
3. Write the time it took you to complete your squeezes in the data table.
4. Repeat steps 2 – 4 for your lab partner.

5. Place your squeeze number and time taken and your partner's squeeze number and time taken on the board.
6. Record 6 other people's data (you choose), as seen on the board, and transfer to the data table.
7. Create a neat **bar graph** of class data for squeeze number. You should have eight bars in total on your graph, including you and your partner. Your x axis on the bar graph should be students by initials.
   Your y axis on the bar graph should be squeezes by number.
8. Create a neat **line graph** of class time. You should have eight points in total on your graph, including you and your partner. Your x axis for the line graph should be students by initials (there should be 8 people). Your y axis for the line graph should be time in minutes.

Data table:

Table 14: Lactic Acid Activity Data

Name	Number of squeezes	Time taken (min)

Questions:

1. Why did you have to stop squeezing?

2. What substance was accumulating in your muscle cells because of your over exertion?

3. What molecules were your muscle cells deprived of that resulted in your having to stop squeezing the tennis ball?

4. Looking at your bar graph, how did your results compare to the results of the class?

5. What is the name of the process that was demonstrated in this lab activity?

6. Is the process that occurred in this lab activity aerobic or anaerobic?

Name: ____ Date: _____________ Hour: _____

Optimal Enzyme Activity

Determining how pH and Temperature Affect the Activity of α-Amylase (a Starch-Degrading Enzyme)

Figure 19: Six-Well Plate

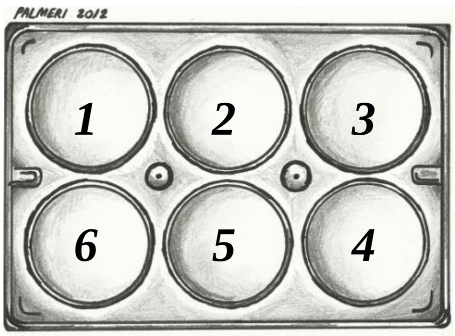


Figure 20: Graduated Pipette

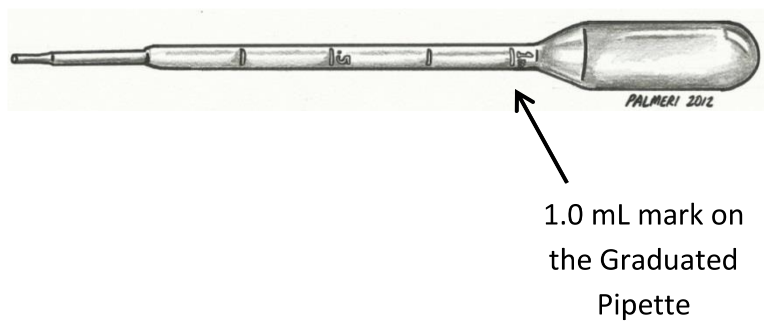


Table 15: Six-Well Plate Organization

EXP # 1 (Temp)		EXP # 2 (pH)	
1	Coldest	1	pH 3.0
2	↓	2	pH 4.0
3		3	pH 5.0
4		4	pH 6.0
5		5	pH 7.0
6	Hottest	6	pH 8.0

Introduction:

Enzymes control numerous reactions involved in the metabolic activities of different organisms. One well-known enzyme is **amylase**, an enzyme that is responsible for **catalyzing** the breakdown of **starches** into **sugars**. Amylase can be found in human saliva and other organs associated with the digestions of food. As you might expect, plants also contain amylase. Many plants store starch, which must be broken down first into simple sugars and eventually converted into cellular energy. Amylase is the enzyme responsible for the initial breakdown of starch.

Purpose / Question:

In today's laboratory, you will investigate how 2 different factors affect the activity of the enzyme amylase. The 2 variables we are testing are pH and temperature. Upon completing this exercise, we hope to answer the following question:

What are the optimal pH and temperature conditions that allow amylase to break down starch the fastest?

Basic Laboratory Explanation and Preparation:

The enzyme amylase will be added to a starch solution. After a given amount of time, an acidic iodine solution will be added to stop the starch breakdown. Any remaining starch will turn blue/purple in the presence of the iodine. We will measure the relative darkness with a software program (Image J) to determine how much starch was degraded and how much remains.

Before conducting this laboratory investigation, it is assumed that the following solutions and materials will be prepared:

- *A large volume of 0.1m Phosphate Buffer (pH = 6.0)*
- *Appropriated 0.1M Phosphate and Acetate buffers with pH values of 3.0, 4.0, 5.0, 6.0, 7.0, and 8.0*
- *α-Amylase stock solution (2.5 mg/mL) – Dilute as needed.*
- *20 g/L soluble potato starch stock solution*
- *Buffered starch solutions – Mix 1:1 to achieve 10g/L buffered starch solutions (pH 3.0 – 8.0)*
- *Iodine IKI dropper bottles (6.0 g KI + 0.6 g I in 100 mL DI – Diluted 1:20 w/0.05M Hydrochloric Acid)*

Procedure – Experiment #1 (Temperature):

1. In locations around the laboratory there should be water baths holding test tubes filled with 5.0 mL of starch solution and a second test tube containing a small volume of the amylase enzyme.
2. Remove a set of test tubes from the lowest temperature water bath (0°C) and quickly return to your lab table.
3. Prepare your stopwatch.
4. Using a graduated pipette, transfer 1.0 mL of amylase enzyme into the test tube containing the starch solution. Gently swirl the test tube to mix.
5. Immediately start the stopwatch.
6. After **1.5 minutes** add 10 drops of the acidic Iodine solution (this stops the reaction).
7. Pour the contents of the starch test tube into the 6-well plate. (See the diagram on the 1st page)
8. Repeat this procedure at the various temperatures that are available.
9. Scan the 6 well plate in the flat-bed scanner – this will be completed by Mr. Palmeri. The scanned image will be available in the X drive.
10. Analyze the results using Image-J in the computer lab (use the procedure below).

Procedure – Experiment #2 (pH):

1. In the laboratory there will be 6 different stations for obtaining starch solution (pH 3.0, 4.0, 5.0, 6.0, 7.0, and 8.0). Start with the lowest pH.
2. **RINSE YOUR TEST TUBE!!!**
3. Go to the pH 3.0 station. Transfer 5.0 mL of starch solution into you test tube. Return to your lab-station.
4. Prepare your stopwatch.
5. Transfer 1.0 mL of the amylase enzyme into the test tube containing starch solution.
6. Start your stopwatch.
7. After **2.0 minutes** add 10 drops of the acidic Iodine solution (this stops the reaction).
8. Pour the contents of the starch test tube into the 6-well plate. (See the Diagram above)
9. Repeat this procedure at the various temperatures that are available.
10. Scan the 6-well plate in the flat-bed scanner – this will be completed by Mr. Palmeri. The scanned image will be available in the X drive.
11. Analyze the results using Image-J in the computer lab (use the procedure below).

Image J Instructions:

1. Open the Image J program from the computer's desktop.
2. Click **"File"** → click **"Open"** → look in the **"X Drive – Palmeri Folder"** for the Image of the 6-well plate that Mr. Palmeri scanned.
3. Once the image is opened, click on **"Image"** → **"Color"** → click on **"Split Channels"**
4. Close out the red and green channel images. Zoom in on the appropriate portion of the blue channel image.
5. Select the "Oval" or elliptical tool.
6. On the image, starting with well #1, select a large and uniformly dark circular area.
7. Click **"Analyze"** → Click **"Measure"**. Numeric values will post in a new window called "Results".
8. Repeat this procedure for all of the wells.
9. Record the mean value in the result window into the data table on this lab worksheet.

Analysis:

1. Use the standard curve provided to determine the starch concentrations at each temperature and pH.
2. Graph the results of each experiment separately in the graphs included on this lab worksheet.

Data:

Table 16: Temperature Data – Starch Degradation by Enzyme Amylase

Table 17: pH Data- Starch Degradation by Enzyme Amylase

Experiment #1 - Temperature		
Temperature (C°)	Mean Image J Value	Starch Concentration (g/L)

Experiment #2 - pH		
pH	Mean Image J Value	Starch Concentration (g/L)
3.0		
4.0		
5.0		
6.0		
7.0		
8.0		

Use the "Mean Image J Value" and the "Standard Curve" below to determine the starch concentration

Standard Curve:

Prior to conducting this lab, establish a standardized curve

- ***Starting with the most concentrated starch sample, perform a step-wise dilution to achieve a consistent range of starch solutions. Add ten drops of acidic iodine to develop color in each sample. Using ImageJ, determine quantitative values and convert these values to established starch concentrations. Students will reference this curve when analyzing their obtained values (when determining their remaining starch concentrations related to ImageJ values).***

Post-Lab Graphing:

Graph the results of each experiment on the following page. Plot the respective points and connect with a smooth line. Remember to set your graphs up correctly (Independent variable on the X-axis). Label each axis, indicate the units, and include a title for each graph.

Name: ____ Date: _____________ Hour: _____

Optimal Enzyme Activity

Determining how pH and Temperature Affect the Activity of α-Amylase (a Starch-Degrading Enzyme)

Post-Lab Questions:

1. What are the independent and dependent variables in each experiment?
   Experiment #1:
   - Independent Variable: ____
   - Dependent Variable: ____

   Experiment #2:
   - Independent Variable: ____
   - Dependent Variable: ____

2. Looking at your graph, what temperature do you expect amylase works best?

3. Looking at your graph, what pH do you expect amylase would work best?

4. Predict: If you conduct this experiment with a starch sample that is 30°C, what do you estimate the remaining starch concentration would be?

5. If you conduct this experiment with a starch sample that has a pH of 7.5, what do you estimate the remaining starch concentration would be?

6. Summarize the results from each experiment (summarize what each graph is "saying").

____

____

____

____

APPENDIX B:

STUDENT EXAMPLES

Figure 21: Investigation #1 Student Example (1)

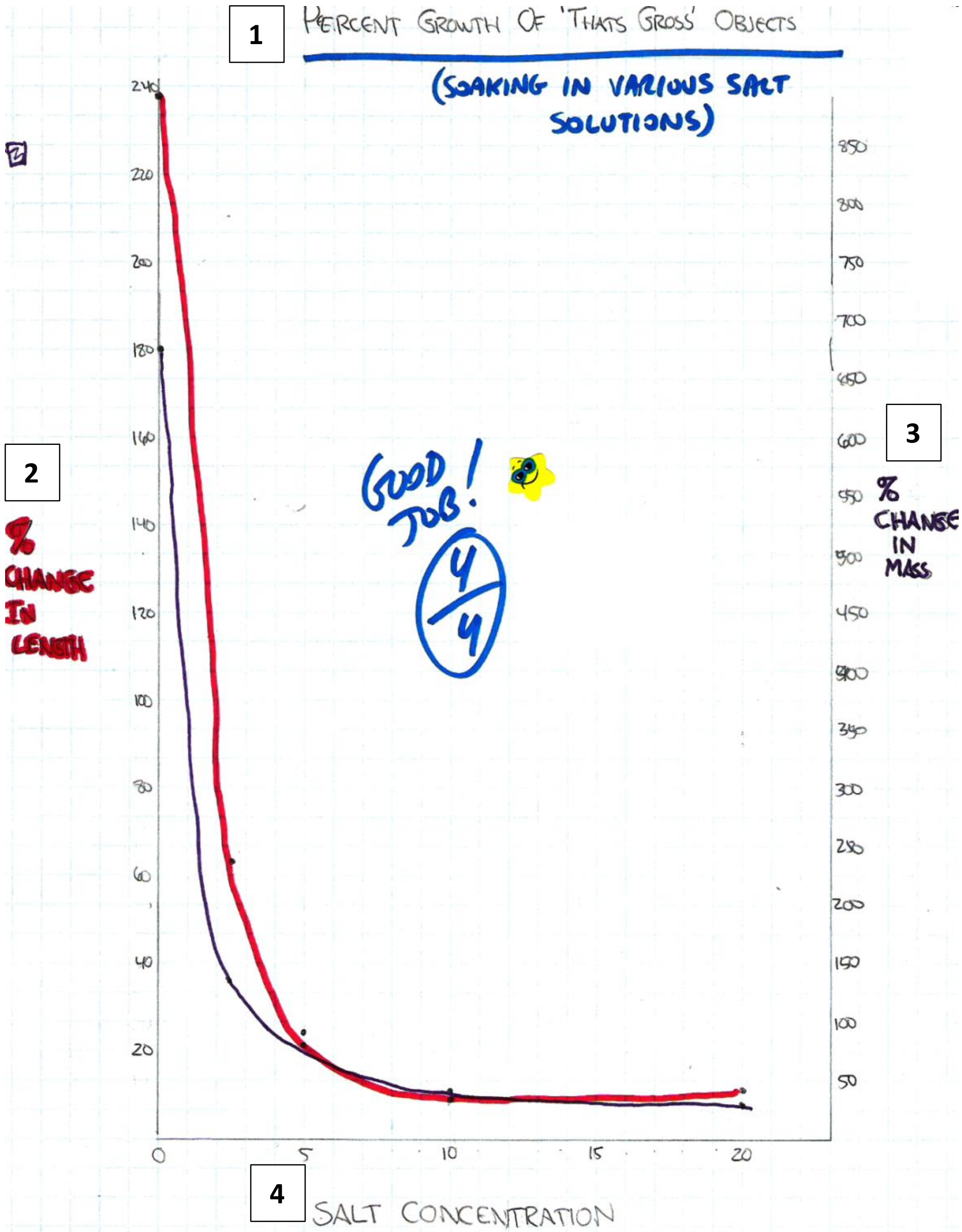


Figure Legend:

1. **Graph Title – "Percent Growth of That's Gross Objects"**
2. **Left Y-axis – % change in length**
3. **Right Y-axis – % change in mass**
4. **X-axis – % salt concentration**

Figure 22: Investigation #1 Student Example (2)

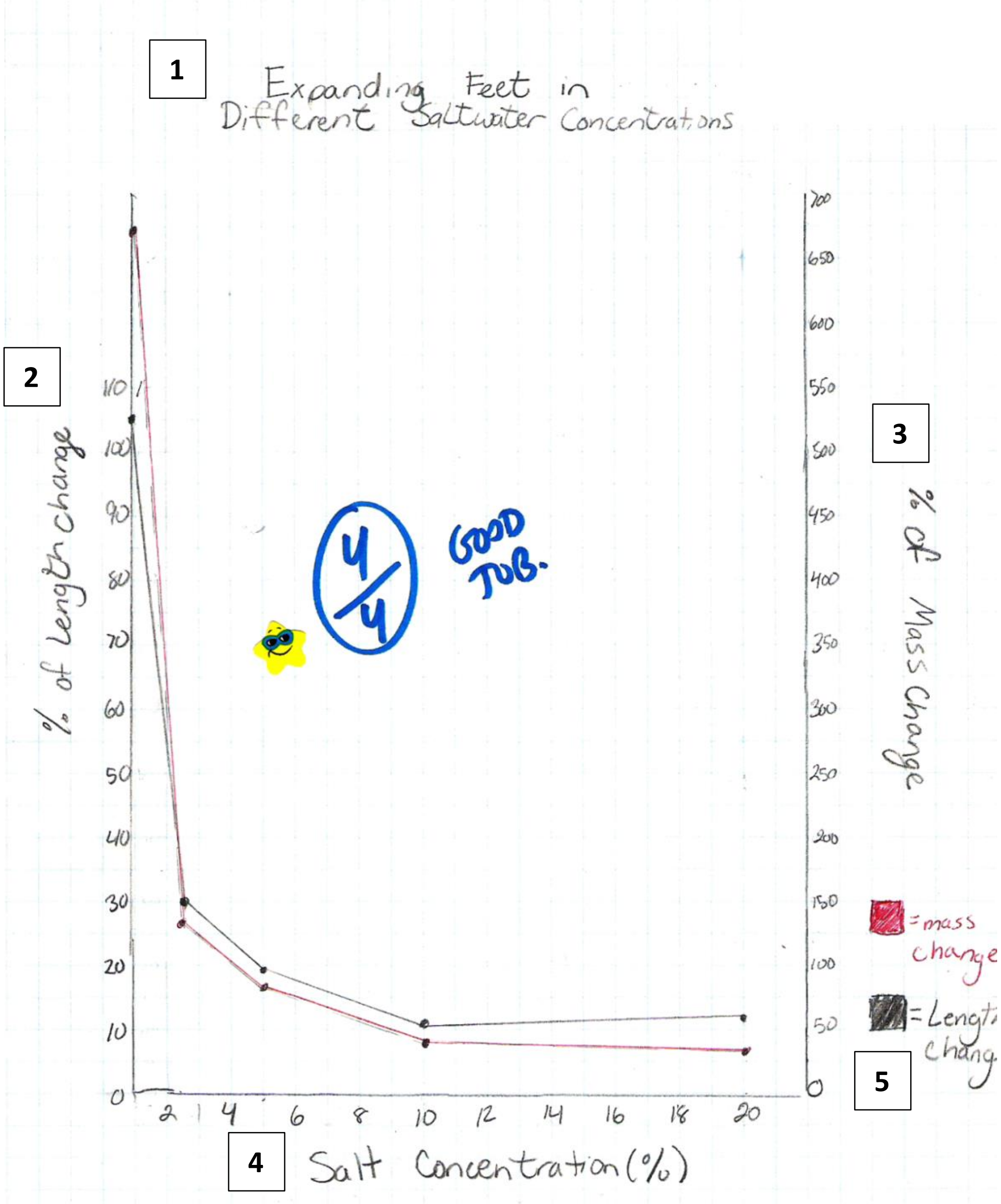


Figure Legend:

1. **Graph Title – "Expanding Feet in Different Saltwater Concentrations"**
2. **Left Y-axis – % of length change**
3. **Right Y-axis – % of mass change**
4. **X-axis – % salt concentration**
5. **Graph Key – color coded (mass change, length change)**

Figure 23: Investigation #1 Student Example (3)

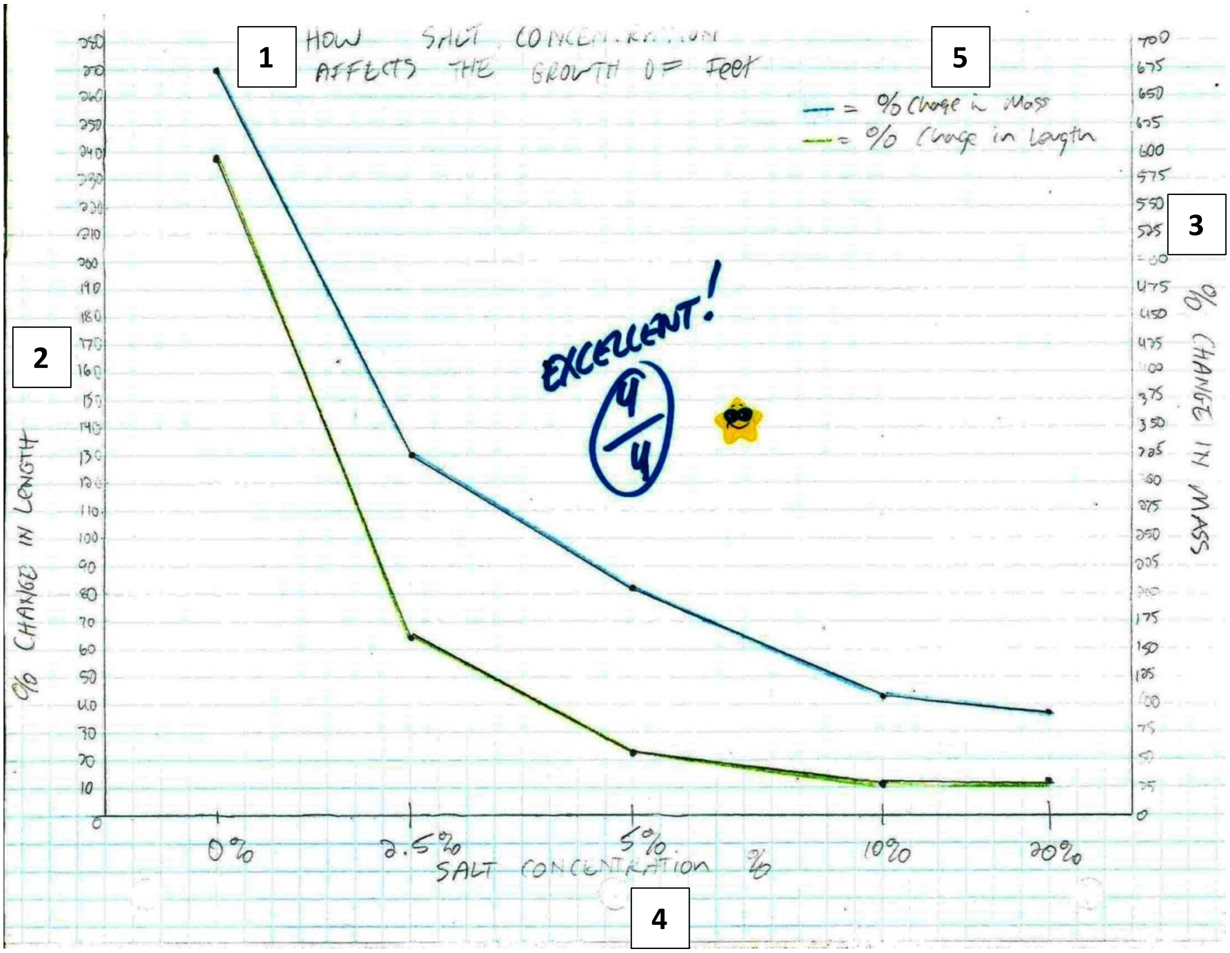


Figure Legend:

1. **Graph Title – "How Salt Concentration Affects the Growth of Feet"**
2. **Left Y-axis – % change in length**
3. **Right Y-axis – % change in mass**
4. **X-axis – % salt concentration**
5. **Graph Key – color coded (% change in mass, % change in length)**

Figure 24: Investigation #2 Student Example

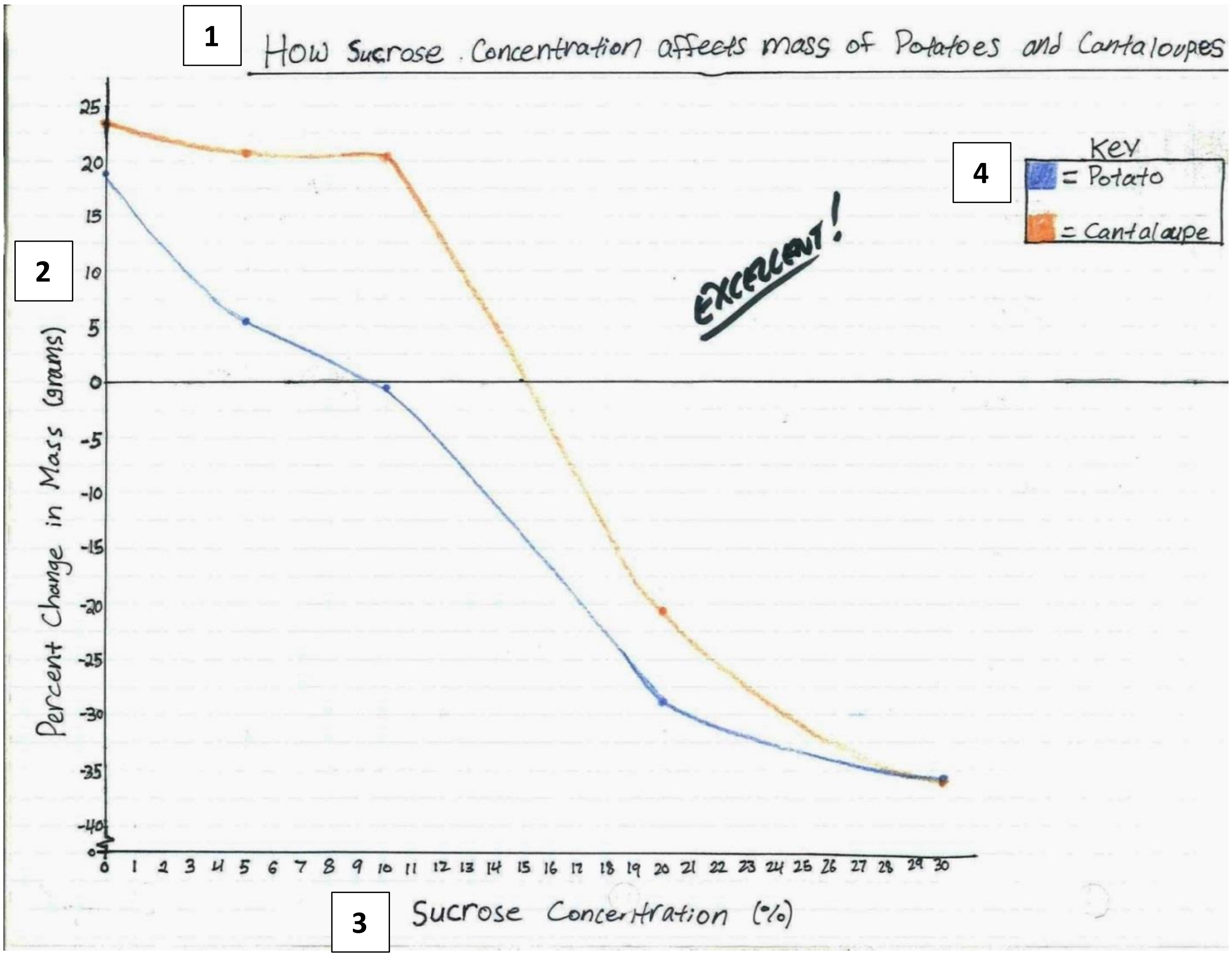


Figure Legend:

1. **Graph Title – "How Sucrose Concentration Affects Mass of Potatoes and Cantaloupes"**
2. **Y-axis – Percent Change in Mass (grams)**
3. **X-axis - Sucrose Concentration (%)**
4. **Graph Key – color coded (Potato, Cantaloupe)**

Figure 25: Investigation #3 Student Example (Color of Light)

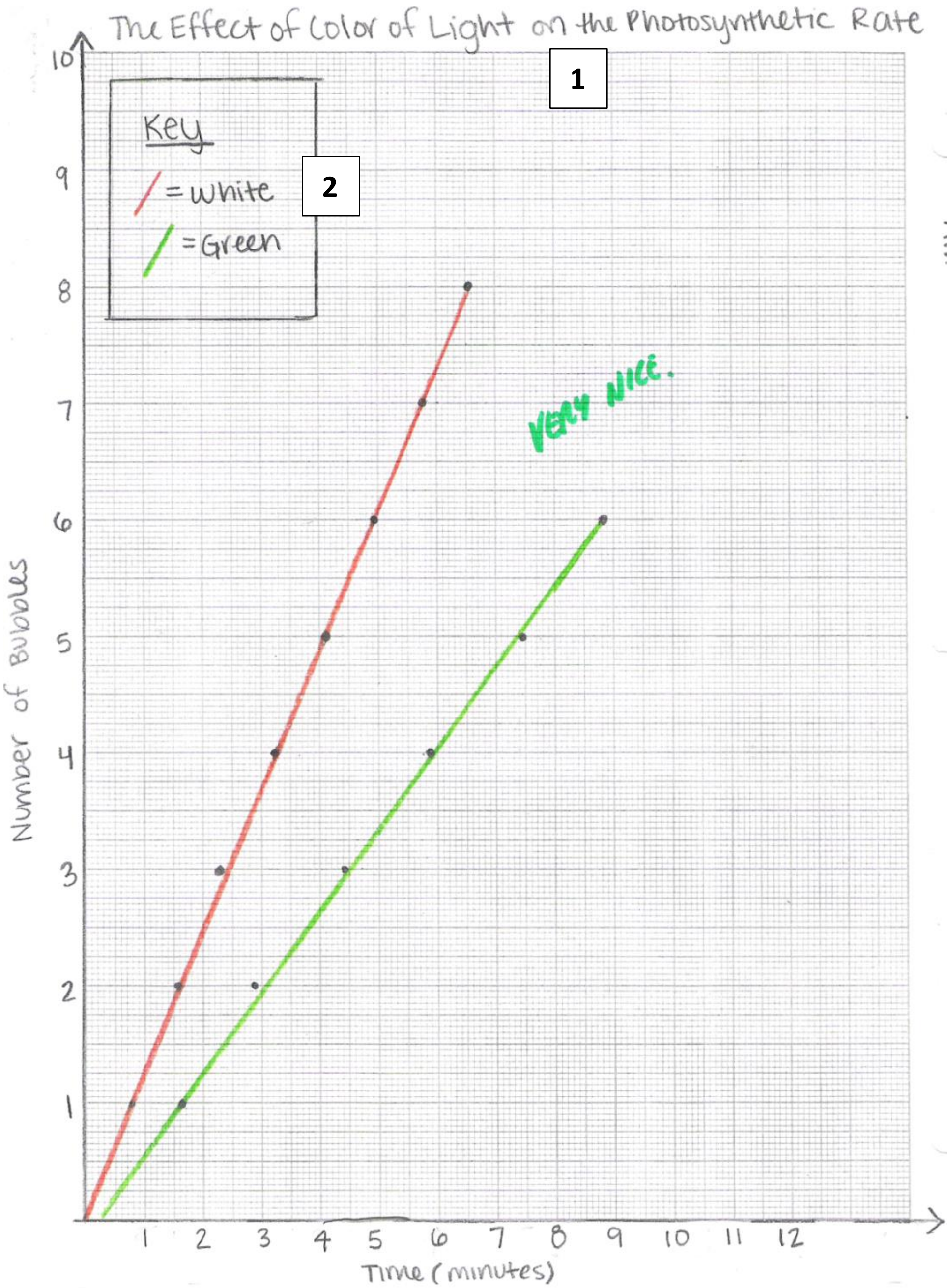


Figure Legend:

1. **Graph Title – "The Effect of Color of Light on the Photosynthetic Rate"**
2. **Graph Key – color coded – (white, green)**

Figure 26: Investigation #3 Student Example (Distance from Light)

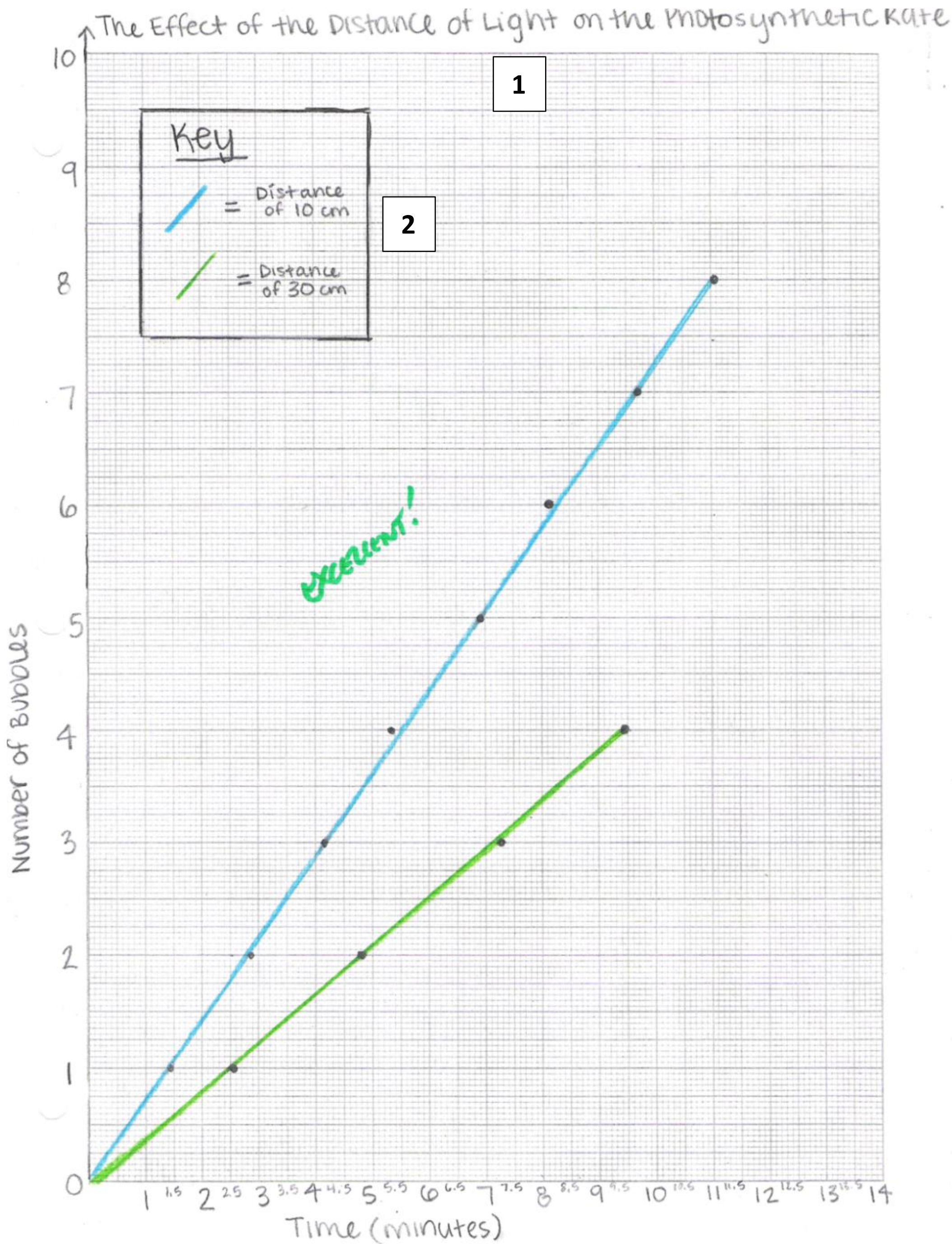


Figure Legend:

1. **Graph Title – "The Effect of the Distance of Light on the Photosynthetic Rate"**
2. **Graph Key – color coded – (Distance of 10 cm, Distance of 30 cm)**

Figure 27: Investigation #5 Student Example (1)

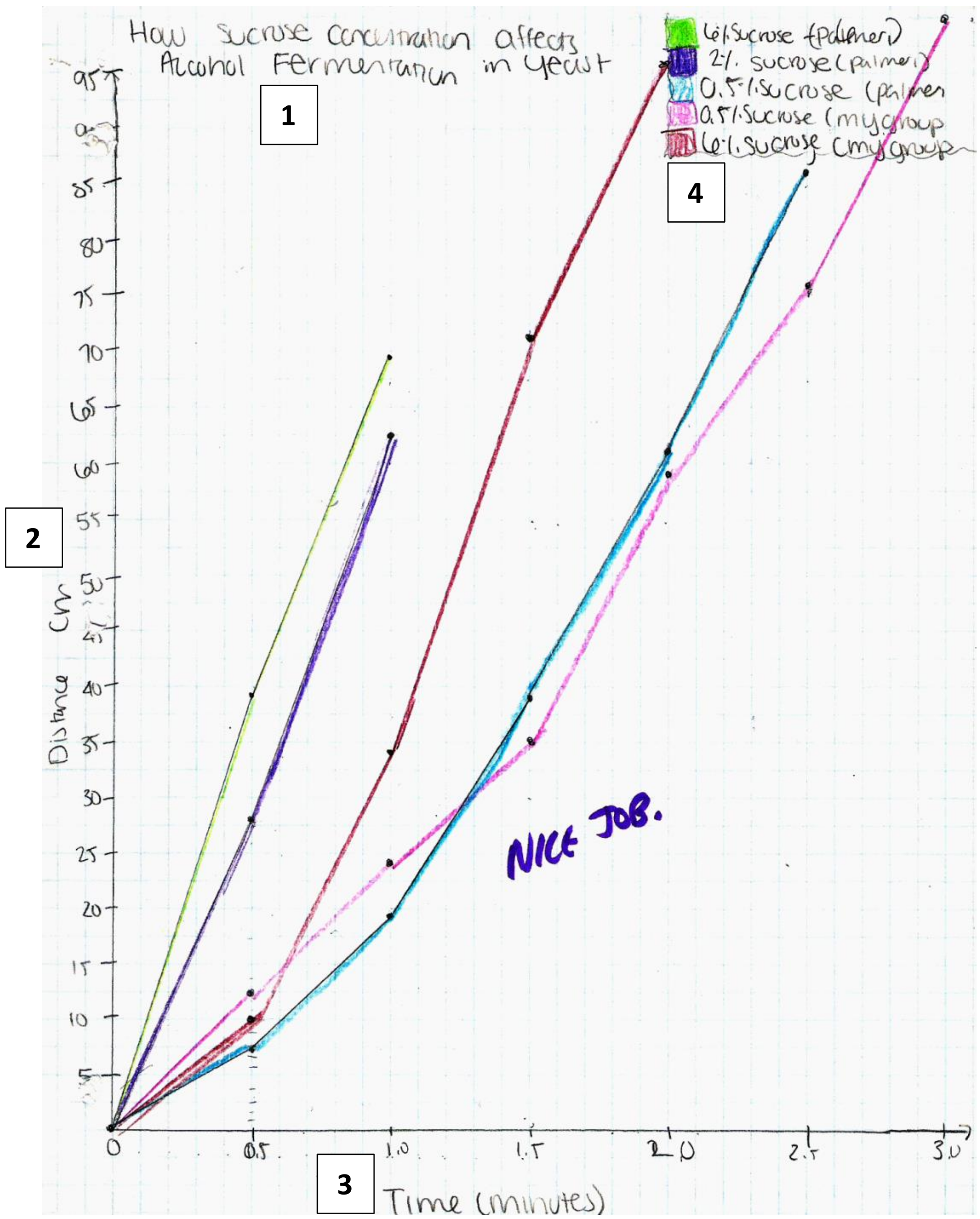


Figure Legend:

1. **Graph Title – "How Sucrose Concentration Affects Alcohol Fermentation in Yeast"**
2. **Y-axis – Distance (cm)**
3. **X-axis – Time (minutes)**
4. **Graph Key – color coded for various sucrose concentrations**

Figure 28: Investigation #5 Student Example (2)

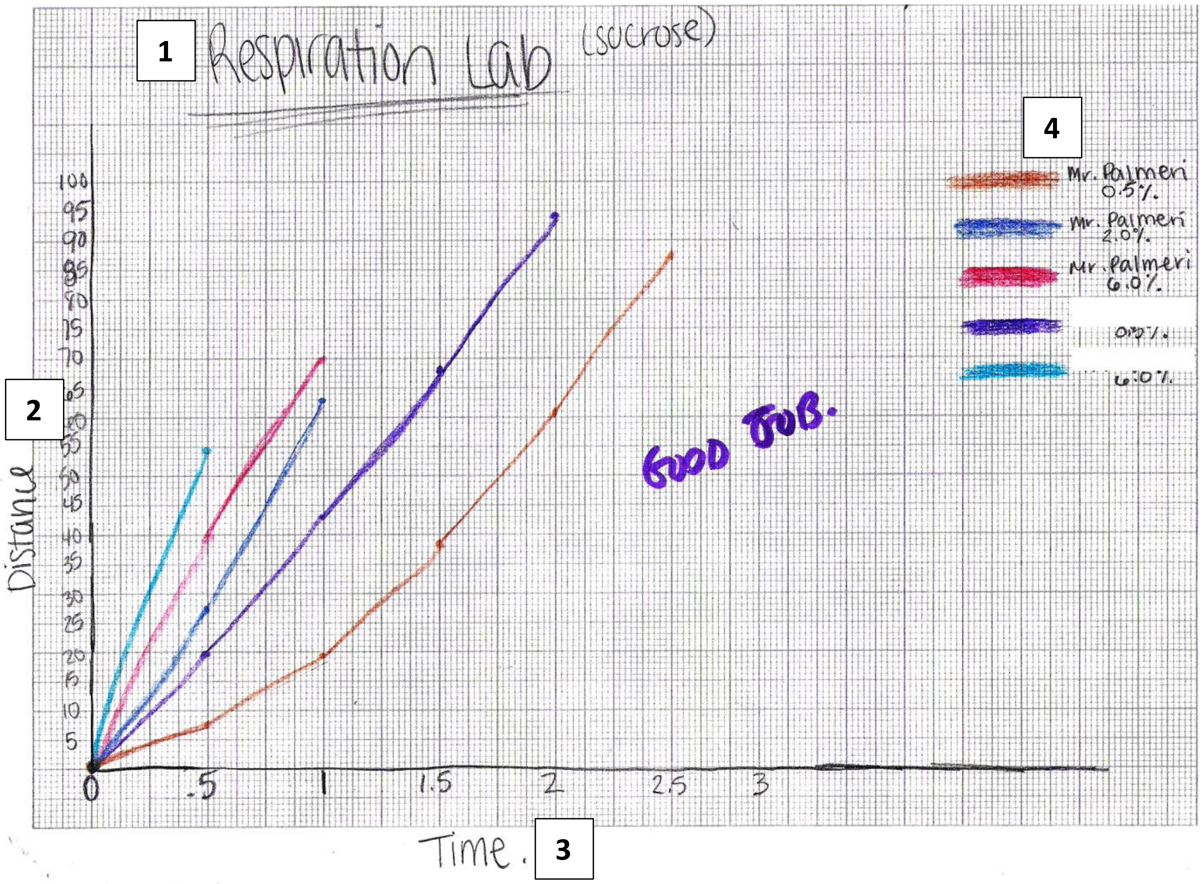


Figure Legend:

1. **Graph Title – "Respiration Lab"**
2. **Y-axis – Distance (mm)**
3. **X-axis – Time (minutes)**
4. **Graph Key – coded for various sucrose concentrations**

Figure 29: Investigation #5 Student Example (3)

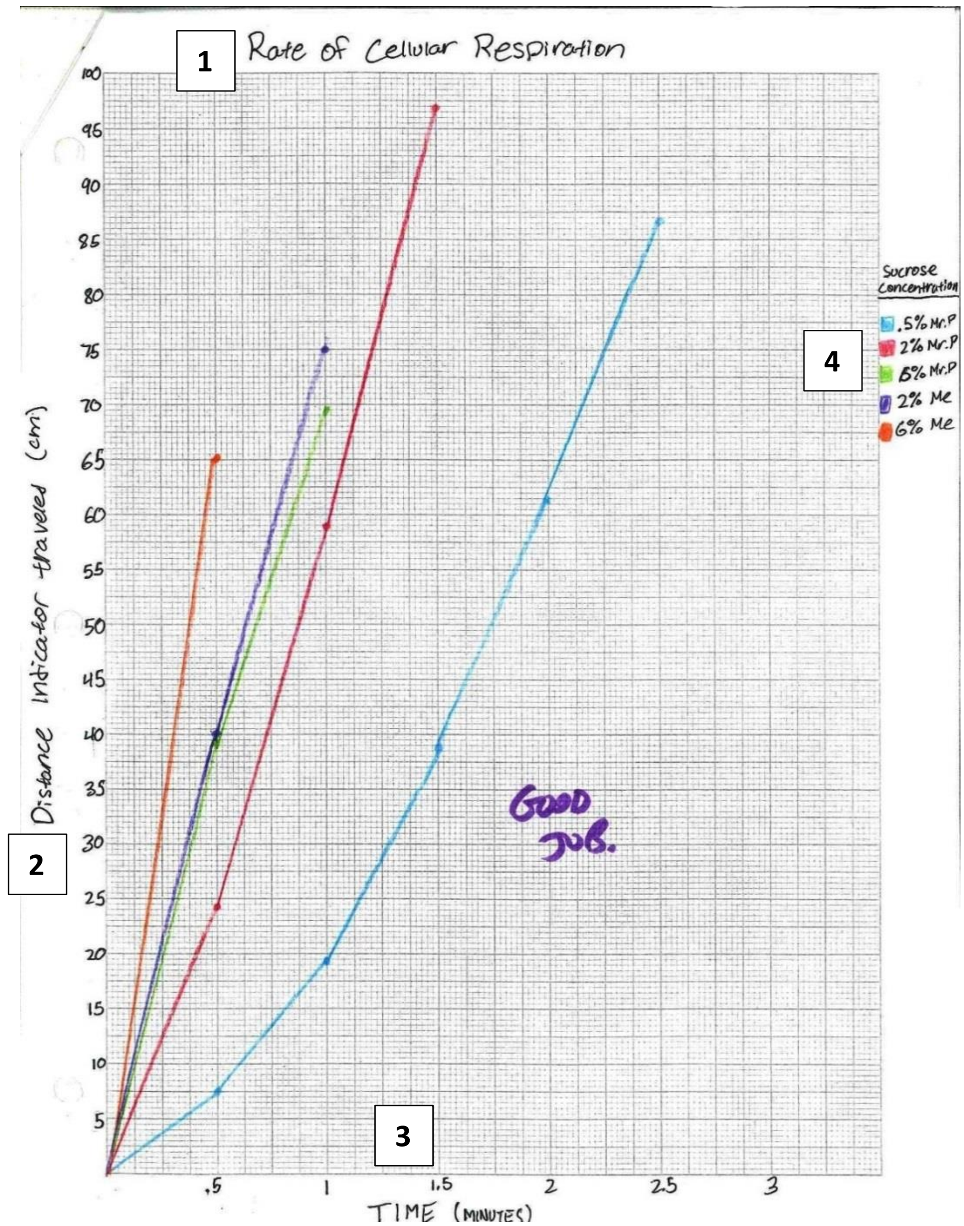


Figure Legend:

1. **Graph Title – "Rate of Cellular Respiration"**
2. **Y-axis – Distance indicator travelled (cm)**
3. **X-axis – Time (minutes)**
4. **Graph Key – coded for various sucrose concentrations**

Figure 30: Investigation #7 Student Example

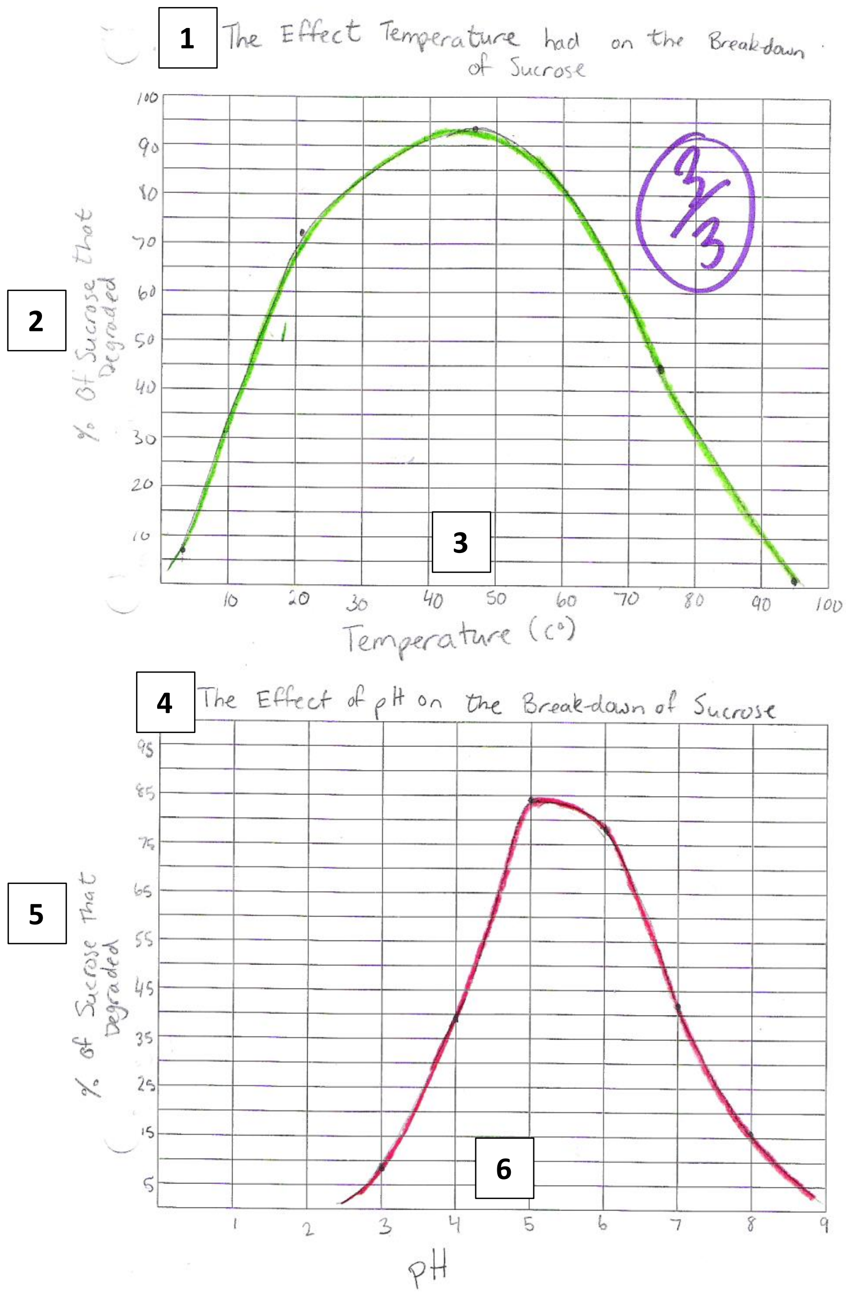


Figure Legend:

1. **Graph Title – "Effect of Temperature…"**
2. **Y-axis – % starch degraded**
3. **X-axis – Temperature (C°)**
4. **Graph Title – "Effect of pH…"**
5. **Y-axis – % starch degraded**
6. **X-axis - pH**

APPENDIX C:

PARENT LETTER AND CONSENT FORM

Figure 31: High School Letterhead – Parental Consent Form (1)

Avondale High School

2800 Waukegan, Auburn Hills, MI 48326 ◆ 248.537.6100
www.avondale.k12.mi.us

Michelle Imbrunone
Principal

Bruce Daniels
Assistant Principal

Julie Lublin
Assistant Principal

PARENTAL CONSENT AND STUDENT ASSENT FORM

Dear Students and Parents/Guardians:

I would like to take this opportunity to welcome you back to school and invite you to participate in a research project, **"Enhancing Graphical Literacy Skills in the High School Science Classroom via Authentic, Intense Data Collection and Graphical Representation Exposure"** that I will conduct as part of the microbiology class this semester. My name is Mr. Anthony Palmeri. I am your science teacher for the first semester of the 2012- 2013 school year and I am also a master's degree student at Michigan State University. Researchers are required to provide a consent form like this to inform you about the study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researchers any questions you may have.

What is the purpose of this research? I have been working on effective ways to incorporate authentic data collection, graph construction and analysis skills and I plan to study the results of this teaching approach on student comprehension and retention of the material. The results of this research will contribute to teachers' understandings about the best way to teach about science topics. Completion of this research project will also help me to earn my master's degree in Michigan State University's Division of Math and Science Education (DSME).

What will students do? You will participate in laboratory investigations activities that will require graph construction and subsequent analysis. These activities will encompass several different units of study, but primarily will focus on the following topics: Photosynthesis, cellular respiration, osmosis, and enzyme catalyzed reactions. You will complete all of the usual assignments, laboratory experiments and activities, computer analysis, class demonstrations, graphing assessments and pretests/posttests just as you do for any other unit of instruction. There are no unique research activities – **participation in this study will not increase or decrease the amount of work that students do.** I will simply make copies of students' work for my research purposes. I am asking for permission from both students and parents/guardians (one parent/guardian is sufficient) to use copies of student work for my research purposes. This project will continue from September 2012 until January 2013.

What are the potential benefits? My reason for doing this research is to learn more about improving the quality of science instruction. I won't know about the effectiveness of my teaching methods until I analyze my research results. If the results are positive, I can further intensify data and graphing activities in other science topics taught in this course. I anticipate that you will benefit by better learning and remembering of course content and you will be more capable of both creating graphs and deciphering those you encounter in the future. Also, enhancing graphical literacy should certainly benefit you when taking college entrance exams such as the ACT. I will report the results in my master's thesis so that other teachers and their students can benefit from my research.

What are the potential risks? There are no foreseeable risks associated with completing course assignments, laboratory experiments and activities, computer analysis, class demonstrations, and pretests/posttests. In fact, completing course work should be very beneficial to students. Another person will store the consent forms (where you say "yes" or "no") in a locked file cabinet that will not be opened until after I have assigned the grades for this unit of instruction. That way I will not know who agrees to participate in the research until after grades are issued. In the meantime, I will save all of your written work. Later I will analyze the written work only for students who have agreed to participate in the study and whose parents/guardians have consented.

How will privacy and confidentiality be protected? Information about you will be protected to the maximum extent allowable by law. Students' names will not be reported in my master's thesis or in any other dissemination of the results of this research. Instead, the data will consist of class averages and samples of student work that do not include names. After I analyze the data to determine class averages and choose samples of student work for presentation in the thesis, I will destroy the copies of student's original assignments, tests, etc. The only people who will have access to the data are me, my thesis committee at MSU, and the Institutional Review Board at MSU. The data will be stored on password-protected computers (during the study) and in a locked file cabinet in Dr. Heidemann's locked office at MSU (after the study) for at least three years after the completion of the study.

What are your rights to participate, say no, or withdraw? Participation in this research is completely voluntary. You have the right to say "no". You may change your mind at any time and withdraw. If either the student or parent/guardian requests to withdraw, the student's information will not be used in this study. There are no penalties for saying "no" or choosing to withdraw.

Who can you contact with questions and concerns? If you have concerns or questions about this study, such as scientific issues, please contact the researcher, [Mr. Anthony Palmeri: 2800 Waukegan Street, Auburn Hills, MI 48326; anthony.palmeri@avondale.k12.mi.us; (248) 537-6100 and /or Dr. Merle Heidemann: 354 Farm Lane #118 , Michigan State University, East Lansing, MI 48824; heidema2@msu.edu; 517-432-2152 x 107].

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 207 Olds Hall, MSU, East Lansing, MI 48824.

How should I submit this consent form? If you agree to participate in this study, please complete the attached form. Both the student and parent/guardian must sign the form. Return the form to the Main Office at Avondale High School by 9/18/2012.

Figure 32: High School Letterhead – Parental Consent Form (2)

Avondale High School

2800 Waukegan, Auburn Hills, MI 48326 ◆ 248.537.6100
www.avondale.k12.mi.us

Name of science course: **Microbiology**
Teacher: **Mr. Anthony Palmeri**
School: **Avondale High School**

Parents/guardians should complete this following consent information:

I voluntarily agree to have ______________________________________ participate in this study.
(print student name)

Please check all that apply:

Data:

☐ I give Mr. Anthony Palmeri permission to use data generated from my child's work in this class for his thesis project. All data from my child shall remain confidential.

☐ I do not wish to have my child's work used in this thesis project. I acknowledge that my child's work will be graded in the same manner regardless of their participation in this research.

Photography, audiotaping, or videotaping:

☐ I give Mr. Anthony Palmeri permission to use photos, audiotapes, or videotapes of my child in the class room doing work related to this thesis project. I understand that my child will not be identified.

☐ I do not wish to have my child's images used at any time during this thesis project.

Signatures:

____ ____________________________
(Parent/Guardian Signature) (Date)

I voluntarily agree to participate in this thesis project.

____ ____________________________
(Student Signature) (Date)

*****Important*****

Seal this form in the attached envelope and return to the Avondale High School Main Office.

APPENDIX D:

ASSESSMENT TOOLS

Name: ____ Date: ______________ Hour: _____

Graphical Literacy Pre-Assessment: Part 1

<u>Table 18</u>: Part1, Question #1 Data

Year	Methane Concentration (ppb)	Average Temperature (°C)
1700	**460**	**7**
1725	**410**	**4**
1750	**645**	**16**
1790	**450**	**10**
1805	**440**	**6**
1825	**390**	**5**
1850	**350**	**4**
1860	**700**	**15**
1875	**505**	**9**
1900	**400**	**8**
1925	**390**	**9**
1950	**375**	**10**
1975	**605**	**13**

<u>Graphing Problem #1</u>:

Methane is a greenhouse gas. Using different data collection methods, climate scientists have determined the atmospheric methane concentrations and average temperatures in a high mountain glacier during a 275 year long period (See Figure 1).

<u>Instructions</u>:

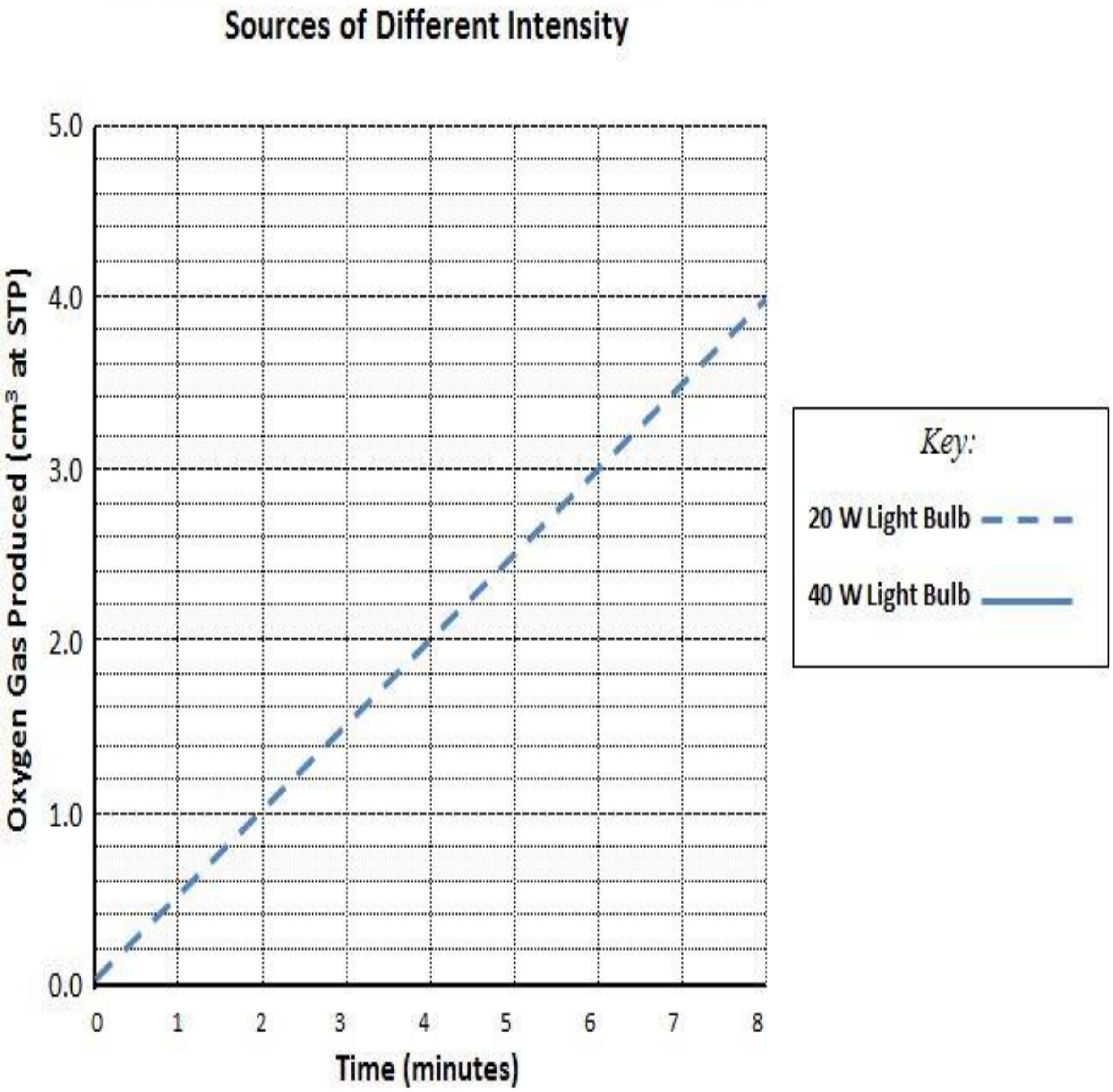
Correctly graph both the methane concentration and average temperature on the graph below. Include all relevant parameters that would be important to a scientist viewing your graph.

<u>Table 19</u>: Part1, Question #1 Graph

Graphing Problem #2:

A student conducts a photosynthesis experiment to see how the wattage of a light bulb affects the amount of oxygen produced during photosynthesis. **Draw a line** representing the photosynthetic rate for the 40W bulb (assuming it is greater than that of the 20W bulb).

Figure 33: Part1, Question #2 Graph- Photosynthesis of a Plant When Exposed to Light

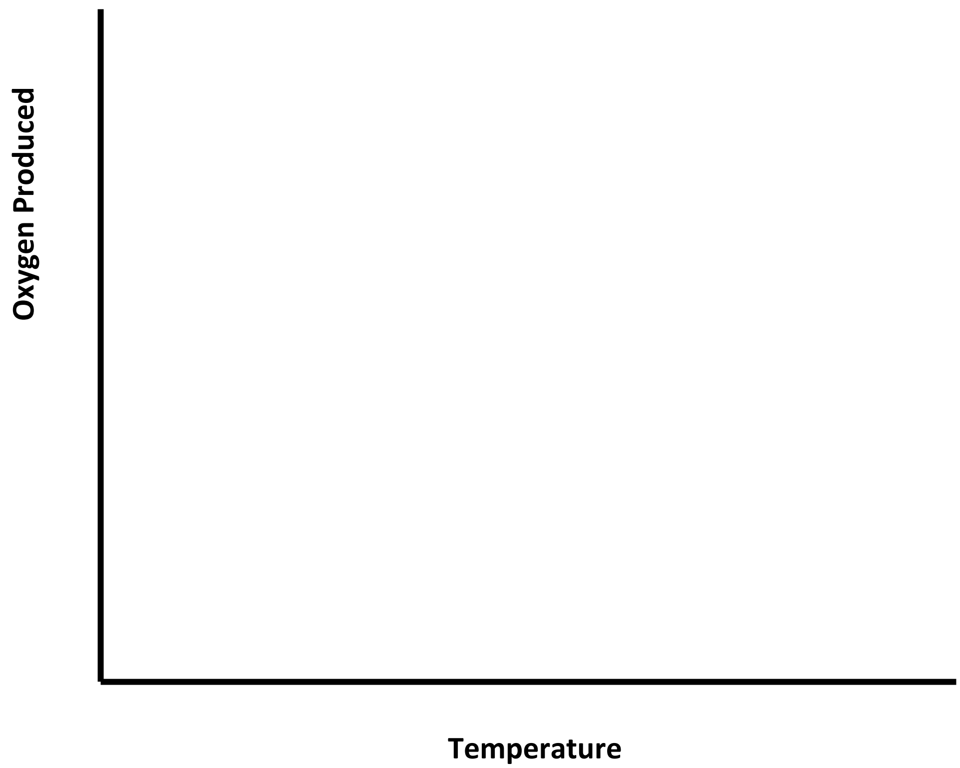


Graphing Problem #3:

The enzyme **catalase** speeds up the decomposition of hydrogen peroxide in living things. Water and oxygen are produced when catalase breaks down hydrogen peroxide. Catalase works slower at extremely low and extremely high temperatures. Catalase works best at intermediate temperatures.

If the activity of catalase was graphed, how would you expect the graph to look? Draw a line that represents the shape you would expect:

Figure 34: Part1, Question #3 Graph

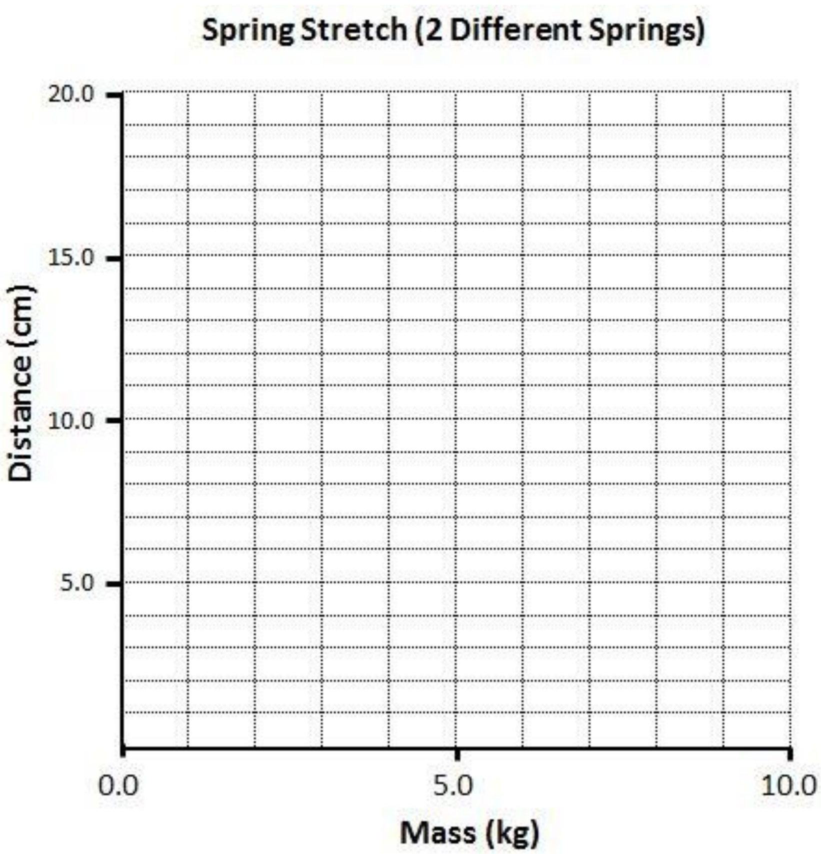


<u>Graphing Problem #4</u>:

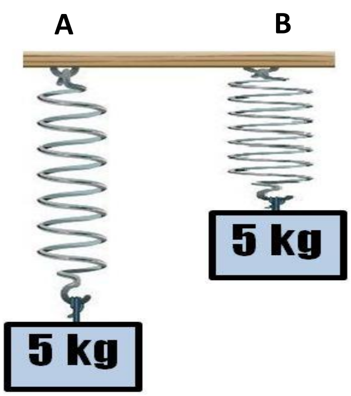
You have 2 different springs, spring "A" and spring "B". **When 5 kilograms are suspended from spring "A" it stretches 10 cm. When 5 kilograms are suspended from spring "B" is stretches 4.0 cm.** The distance a spring stretches due to the amount of weight pulling on it is a linear relationship. You can assume that these springs do not stretch at all (0cm) when there is no weight pulling on them.

Graph the spring-stretch data below and answer the questions that follow:

<u>Figure 36</u>: Part1, Question #4 Graph – Spring Stretch of 2 Different Springs



<u>Figure 35</u>: Part1, Question #3 Illustration



<u>Questions</u>:

1. **About what distance would spring "A" stretch by an 8.0 kg mass?**

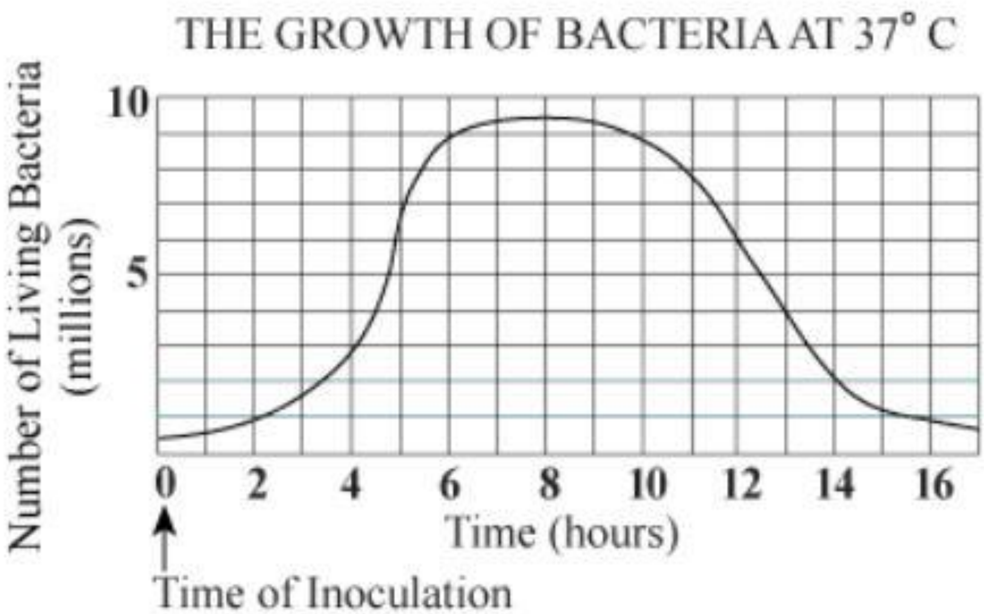
2. **About what distance would spring "B" stretch by an 8.0 kg mass?**

Name: ____ Date: _____________ Hour: _____

Graphical Literacy Pre-Assessment: Part 2

1. A culture tube is inoculated and incubated at 37°C. The resulting bacterial growth is graphed below:

Figure 37: Part2, Question #1 Graph – Growth of Bacteria at 37 Degrees Celsius

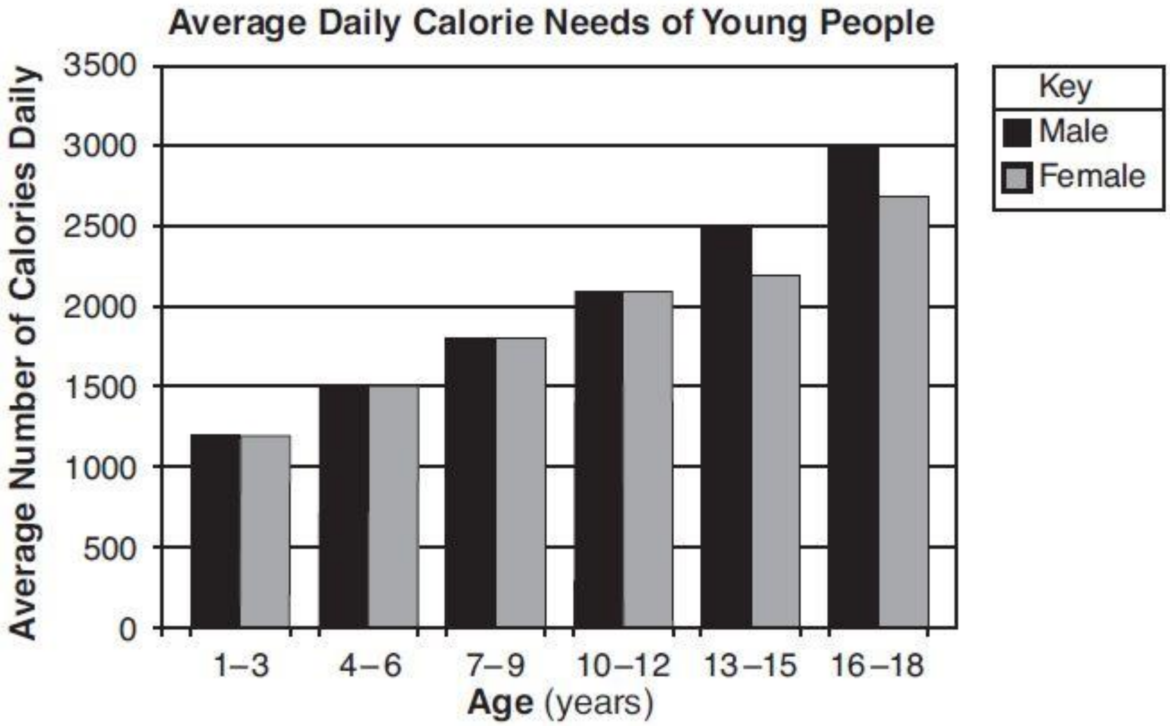


At what time is the number of bacteria increasing at the greatest rate?

A. 16 hours
B. 11 hours
C. 8 hours
D. 5 hours

2. The graph below shows how the average daily calorie needs of young people changes as the get older.

Figure 38: Part2, Question #2 Graph – Caloric Intake



How many more average daily Calories are needed by a 17-year old male than by a 17-year old female?

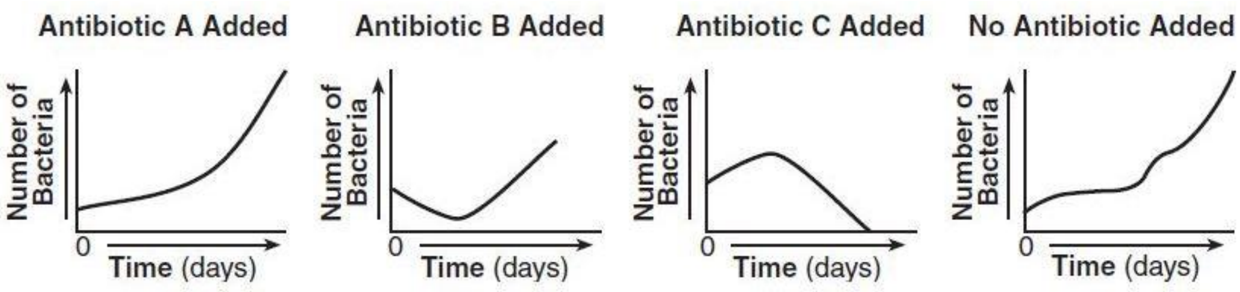
A. 300
B. 500
C. 2700
D. 3000

3. Look at graph provided in the previous question (#2). Which statement is supported by the graph?

A. At age 14, a female needs more daily Calories than a male
B. At age 9, a female needs the same daily Calories as a male
C. An 11-year old child needs twice as many daily Calories as a 6-year old child
D. An 8-year old female needs fewer daily Calories than a 5-year old male.

4. Some species of bacteria are harmful. Antibiotics are chemicals that kill bacteria. Some bacteria are resistant to antibiotics and are not killed by these chemicals. The graphs below show the results of a controlled experiment that was conducted to determine the effectiveness of 3 different antibiotics against a specific type of bacteria.

Figure 39: Part2, Question #4 Graphs – Effectiveness of Different Antibiotics

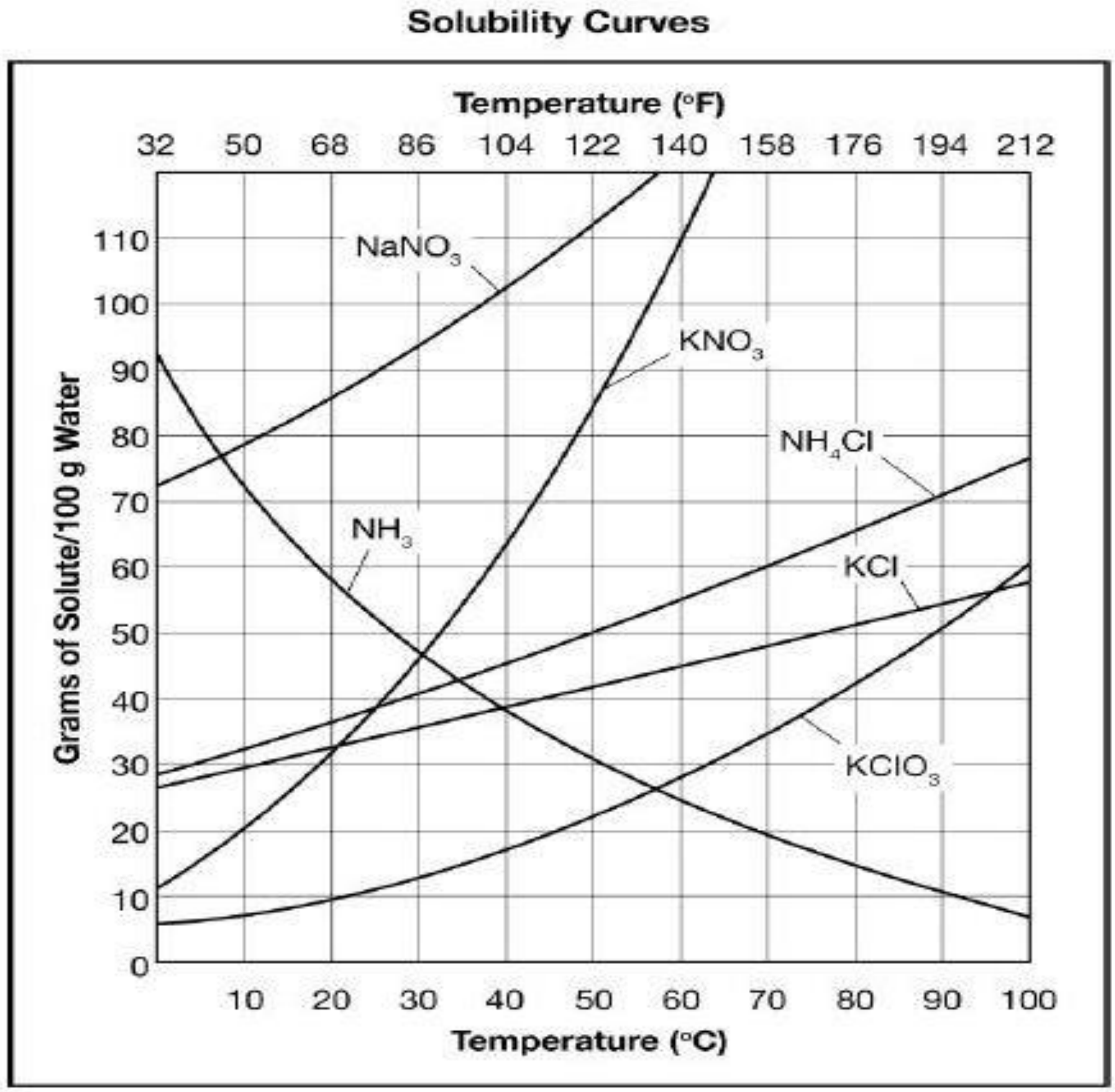


Which conclusion is best supported by the information in the graphs?

A. Antibiotic A continuously slowed the growth
B. Antibiotic B was least effective in controlling the growth
C. Antibiotic C was most effective in controlling the growth
D. Antibiotic A and B slowed the growth

5. The solubility curves below show how many grams of each substance can be dissolved into 100 grams of water at various temperatures.

Figure 40: Part 2, Question #5 Graph – Solubility of Various Substances



Based on the graph above, which of the following statements is TRUE?

A. At 20°C, the maximum amount of $KClO_3$ that can dissolve in 100 grams of water is 20 grams
B. At 20°C, the maximum amount of $NaNO_3$ that can dissolve in 100 grams of water is 45 grams
C. At 50°C, approximately three times as much NH_4Cl can dissolve compared to NH_3
D. At 50°C, approximately twice as much KNO_3 can dissolve compared to KCl

6. The data table on the right shows the number of calories used while doing a variety of exercises.

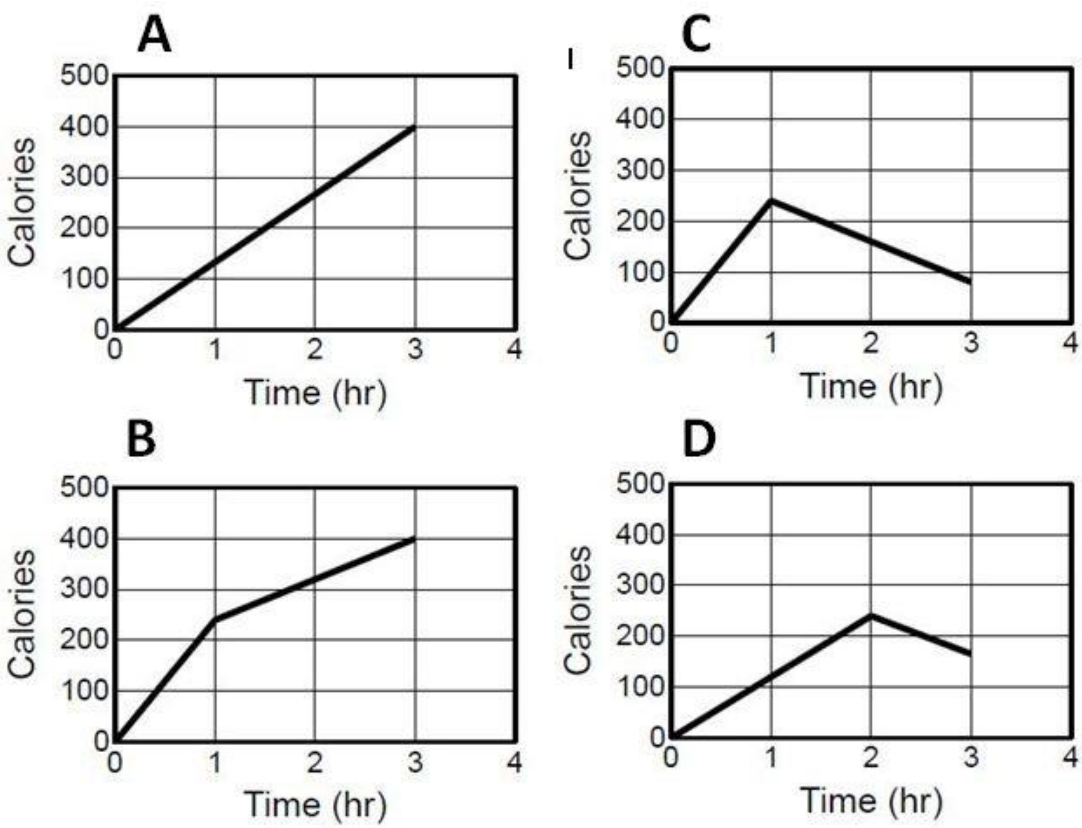
   According to the table, which graph below illustrates the calories used for 1 hour of jogging followed by 2 hours of walking?

Table 20: Part 2, Question #6 Calorie Use Data

Calorie Use Table (by 120 lb adult female)

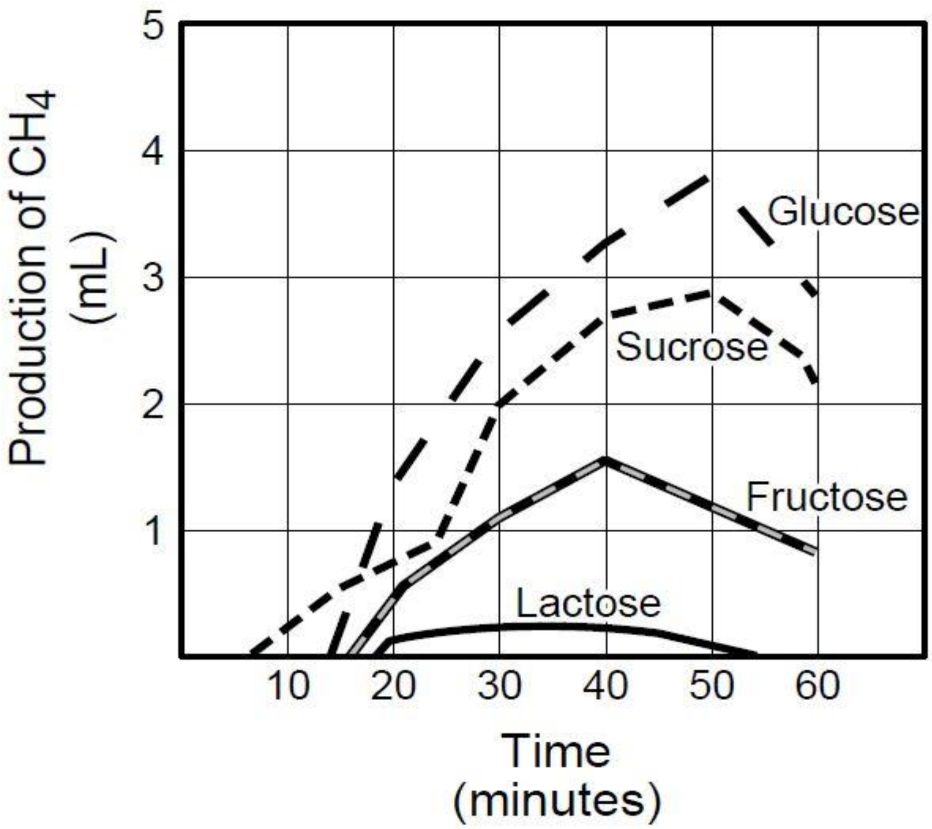
Activity	Calories Used (per hr)
Walking	80
Gymnastics	170
Jogging	240
Tennis	280
Bicycling	320
Swimming	440

Figure 41: Part 2, Question #6 Graph Answers



7. Many Bacteria produce methane (CH_4) as a byproduct when they grow. A measured amount of methane-producing bacteria was placed in four test tubes, each containing a different sugar (fructose, sucrose, lactose, glucose). What conclusion can you draw from this graph?

Figure 42: Part 2, Question #7 Graph – Methane Production of Bacteria



A. These bacteria cannot use lactose very efficiently

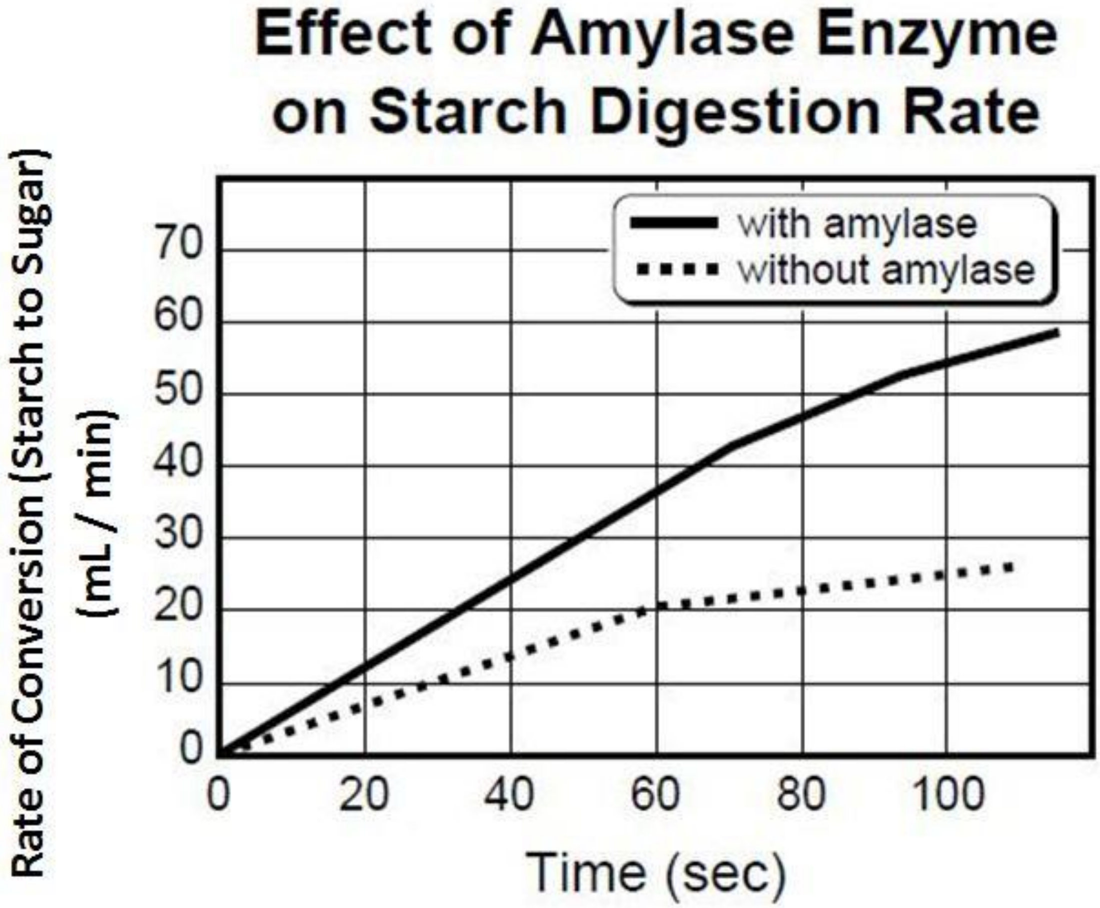
B. Growth is fastest with sucrose

C. All of the sugars were used up after 40 minutes

D. At 60 minutes all of the bacteria were dead

8. Amylase is an enzyme that catalyzes the breakdown of starch. Study the graph below:

Figure 43: Part 2, Question #8 Graph – Digestion of Starch by Amylase



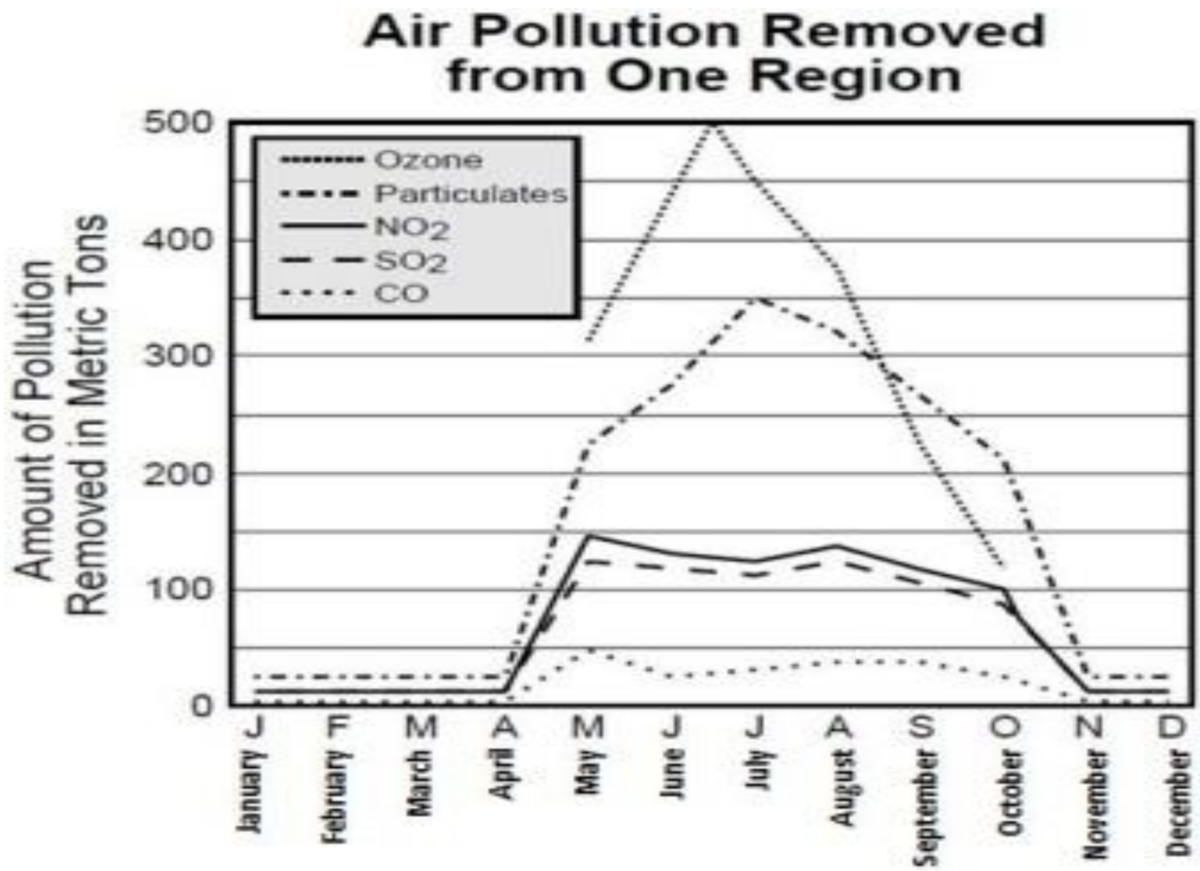
According to the graph, addition of the enzyme amylase caused the reaction to:

A. Slow down
B. Take in heat
C. Give off heat
D. Speed up

9. The graph at the right shows the amount of pollutants removed by trees.

According to this graph, trees are able to remove the greatest amount of which pollutant during the month of October?

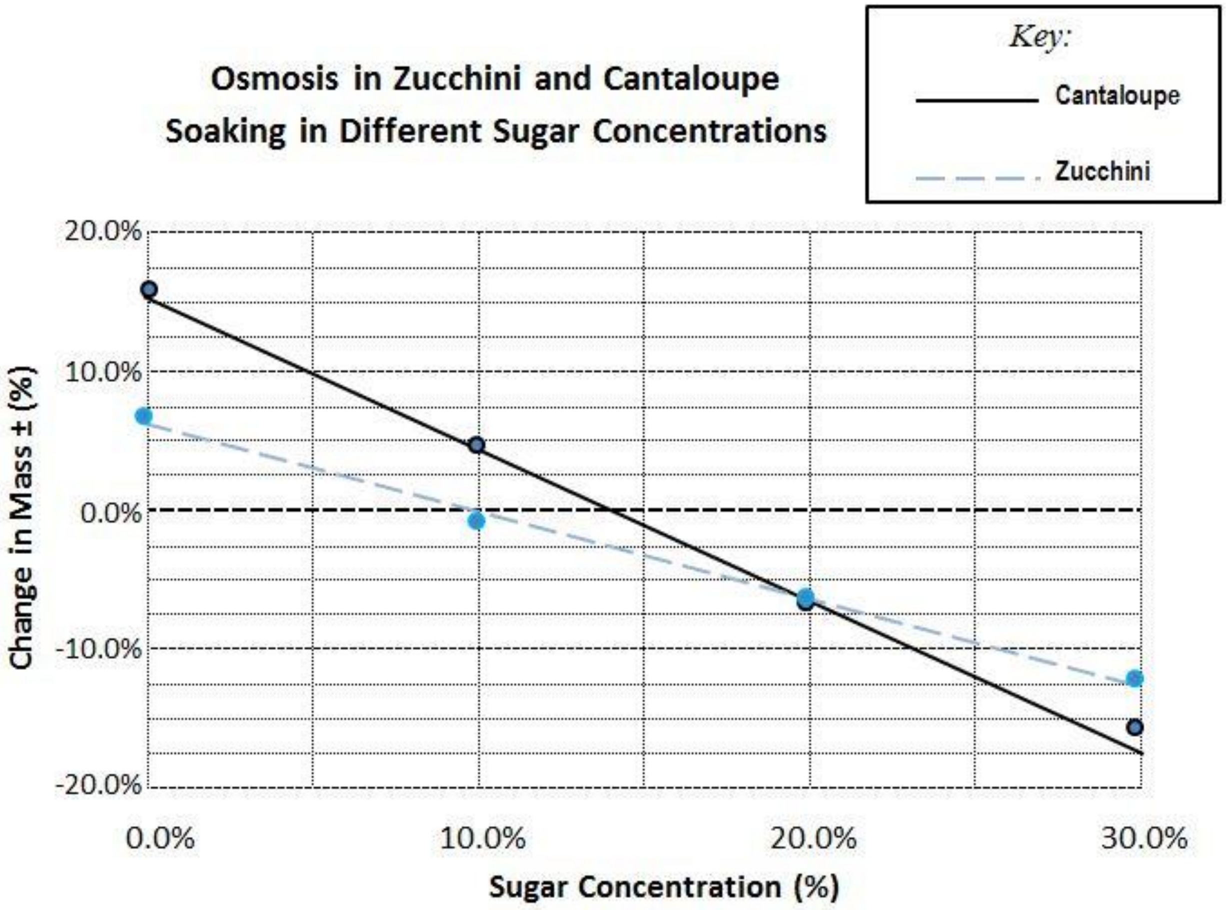
Figure 44: Part 2, Question #9 Graph – Pollution



A. Ozone
B. Particulates
C. NO_2
D. SO_2

10. In an osmosis experiment, equally sized zucchini and cantaloupe pieces were soaked in various concentrations of sugar. The percent change in mass at each concentration was determined and the results were graphed:

Figure 45: Part 2, Question #10 Graph – Osmosis in Zucchini and Cantaloupe



Based on this graph, at what sugar concentration will cantaloupe show no change in mass?

A. 0.0%
B. 7.5%
C. 14.0%
D. 23.0%

Table 21: Scoring Rubric: Graphical Literacy Pre-Assessment: Part 1

Part 1 of the Assessment has a total value of 20 points and will be scored as follows:

Graphing Problem #1:

Point Value (**MAX** → partial**)**	
2/1/.5	2 individual Y axes Labeled (Methane) and (Temperature) with units annotated on each
1/.5	X-Axis (Year) Labeled with units annotated on X axis
1/.5	Key is provided
2/0	Axes oriented appropriately
1/.5	Each axis uses an appropriate and consistent increment
1/.5	A suitable title is provided
2/1/.5/0	A line showing methane concentration is graphed correctly
2/1/.5/0	A line showing average temperature is graphed correctly
Total Possible = 12 pts.	

Graphing Problem #2:

Point Value (**MAX** → partial**)**	
1/.5	Line (Linear) is drawn
1	Slope is greater than the 20W bulb
Total Possible = 2 pts.	

Graphing Problem #3:

Point Value (**MAX** → partial**)**	
2/1/.5	Oxygen level is indicated highest at some moderate temperature value
1/.5	Smooth, bell-shaped curve is drawn
Total Possible = 3 pts.	

Graphing Problem #4:

Point Value (**MAX** → partial**)**	
1	Line for spring A is graphed correctly
1	Line for spring B is graphed correctly
.5	Question 1 answer: 16±0.5 cm
.5	Question 2 answer: 6.5±0.5 cm
Total Possible = 3 pts.	

Table 22: Scoring Rubric: Graphical Literacy Pre-Assessment: Part 2

Question	Answer
1.	**D**
2.	**A**
3.	**B**
4.	**C**
5.	**D**
6.	**B**
7.	**A**
8.	**D**
9.	**B**
10.	**C**

Part 2 of the Assessment has a total value of 20 points.

Each correct response is worth 2 points.

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REFERENCES

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