Supplementing the Learning of Physics with the Focused Instruction of Graphicacy

A Major Qualifying Project
submitted to the faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree in Bachelor of Science in Physics

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Abstract

Graphicacy, or proficiency in using and making graphs, is a useful skill in academia and industry. However, it has been shown in past research that high school students are not learning, or perhaps not understanding, how to read graphs— specifically kinematic graphs of displacement, velocity, and acceleration. My MQP project was based on this notion, and was an investigation into ways to help students become more proficient in graphicacy. I had the opportunity to teach physics at Leominster High School (LHS). The approach for the project was to teach the regular curriculum with a greater focus on graphing and graphing methods for solving physics problems. The results were measured with a pre and post test which assessed students' confidence in graphing, their ability to graph kinematics scenarios, and their ability to draw conclusions from more complex graphs. Results of the posttest were better than the pretest in all categories. These results are promising and demonstrate that if teachers have a more focused instruction on graphicacy supplementary to their normal curriculum, student understanding of graphicacy itself may increase.

> Key vocabulary: *graphicacy* — The term "graphicacy" first appeared in 1965 as a way to broadly describe the use of visualizations as a house plan, farm layout, map of a village, etc. Over time its definition has narrowed; Wainer (1980) introduced the term "graphicacy" to mean the ability to read graphs, defining it as proficiency in understanding quantitative phenomena that are presented in a graphical way.[1]

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[1] Building a Theory of Graphicacy: How Do Students Read Graphs? *Friel & Bright*

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Acknowledgements

I would like to thank my project advisor, Rudra Kafle, as well as the teacher preparation program advisor, Shari Weaver, for their input and expertise in this project, as without them it would not have been possible to complete this project, nor even think to attempt it.

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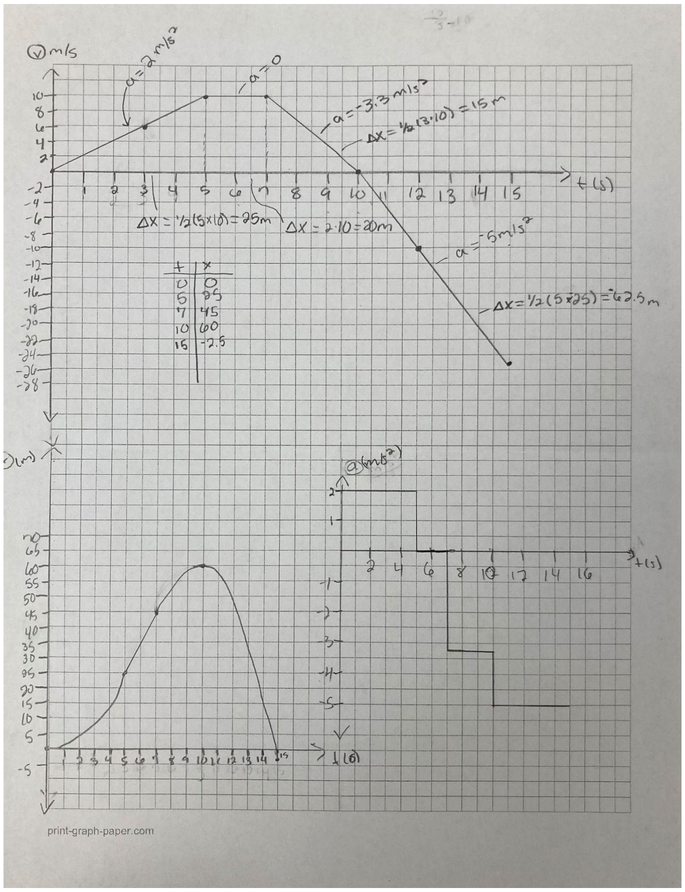
I would also like to thank TJ Noviello, James Sheehan, and Jackie Bonneau, who oversaw my project at Leominster High School. They were a guiding hand to which offered me help when I needed it.

Finally, I'd like to thank the WPI Teacher Preparation Program, the entire faculty and staff of Leominster High School, WPI's Institutional Review Board, and WPI as a whole for giving me the opportunity to carry out such a project.



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Introduction

➢ Overview

The aim of this project is to better prepare students at the high school level to work with graphs in their academic studies, and even beyond. It has been shown that this skill — specifically the concepts behind graphing in general — is lacking in many high school and even college students. In order to be better prepared for college and the workplace beyond, students need to be equipped with the tools to succeed. This project was accomplished by means of the student teaching practicum opportunity afforded by WPI's Teacher Preparation Program. As a student teacher, I taught four different physics classes for 15 weeks. During this time, my primary goal was to teach to the best of my ability, while also incorporating the project goals into the normal physics curriculum. The method by which the study was done was by creating lesson plans throughout the semester that specifically targeted graphing skills. The results of the research were measured with a pre and post test administered to the students in my classes.

➢ Motivation

The familiar adage that a picture is worth a thousand words holds true, especially in education. When it comes to data, the entire purpose of a graph is to show a relationship that would be difficult to describe with just words. We live in a world where the rate at which knowledge doubles can be measured in months instead of decades[2]. Therefore, the ability to mentally process information with a graph is becoming a vital skill. In the STEM fields especially, data analysis and interpretation are essential for progressing in your field, which indicates that creating and reading graphs should be taught early and often in schools. After all, humans are visual learners, and graphs are helpful for seeing relationships that would otherwise be muddled in a sea of words and numbers. That is why it is so important for students to learn how to read and create graphs. The motivation of this project comes from the recognition that students coming out of high school and in college don't know how to properly interpret or create graphs, especially in physics. But by using graphs as a vehicle for learning, the expectation is that students will be more adept and confident in their ability to read and create graphs.

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[2] Teaching for Deeper Learning *by Jay McTighe and Harvey F. Silver*

➢ Objectives

The objectives of this project are to increase student confidence in their graphing ability, reinforce graphing as an essential skill for physics, teach students how to read unfamiliar graphs, and acquaint students with kinematics graphs (since these are an essential learning step for conceptual physics knowledge).

Background

➢ Graphicacy

According to Merriam-Webster, the term “graphicacy” means “the ability to understand, use, or generate graphic images (such as maps and diagrams)”. That is why this term is used throughout this project report to describe the ability to understand and create graphs. In general, it is assumed that a greater understanding of graphicacy indicates a more complete skill set for graphical analysis and graph creation.

➢ Teacher Preparation Program

The first reason this project became possible was due to the WPI Teacher Preparation Program, as it was only through this program that I was given the opportunity to be a full-time teacher at a nearby high school. This program aims to prepare students who may want to pursue teaching as their career for the unique challenges of the future. A teacher candidate in the program can earn a Massachusetts-authorized initial teaching license simultaneously with a four-year college degree. Candidates must take four required classes and complete the 15-week teaching practicum, during which the student must complete at least 300 hours in the classroom, with at least 120 hours being teacher-of-record hours. Specifically for physics majors, this teaching practicum may also be used as an MQP project, given that the practicum also incorporates a research component.

➢ Overview of Leominster High School

Every year, WPI teacher candidates are placed at partnered schools in or near the Worcester community. My placement was at Leominster High School (LHS) under Sarah Friberg, my supervising practitioner. LHS is a public school that serves the diverse community of Leominster, MA with a population of approximately 2,000 students. It is both a normal high school and a trade school. I eventually took over four physics classes at LHS, three of which were what are called "general" physics classes, and one "honors" physics class. The difference between these classes is the depth and pace that the class takes to get through the course material, with the honors physics class tackling more challenging problems. There are no extra requirements for students to enter into the honors physics class. At LHS, physics is not a requirement for graduation, although taking four science classes is a requirement, which causes many students to take physics to fulfill that requirement. The overarching units that teachers at LHS try to cover during a year in physics, both for general and honors, are:

1. Introduction to physics
2. 1D Kinematics
    a. Distance vs displacement
    b. Speed vs velocity
    c. Acceleration
    d. Honors only: kinematics graphing
3. 2D Kinematics
    a. Free fall
    b. Projectile motion
4. Newton's laws of motion
5. Uniform circular motion
6. Energy, work, and power
7. Momentum
8. Waves and sounds
9. Electromagnetic spectrum
    If time allows:
10. Optics
11. Electrostatics and circuits
12. Thermodynamics

A photo taken early in the morning at Leominster High

The teaching practicum uses a staggered takeover process, so that the student teacher is not overwhelmed. Due to this, I took over the general classes when they reached velocity, and took over the honors class after they finished kinematics graphing.

In addition, due to the ongoing COVID-19 pandemic, this was the first time students were back to in-person learning in over a year, and there were many factors that caused fluctuation in class sizes throughout the semester. My smallest class was 14 students (general physics, period three), and my largest was 28 students (honors physics).

Two different angles of the classroom where I was teaching throughout the entire practicum.

➢ Need for project

As mentioned before, the reason that this project was done was because it's been shown that students lack a good understanding of graphicacy. Graphing is a valuable skill in any STEM field, not just physics. Even a greater exposure to graphs in more depth could be valuable later on in a student's education and career. When a student gets to college, professors may use graphs without first verifying that students understand how to adequately read them. In lab courses, students will be expected to be able to create their own graphs from data. As information increases, more is expected of students, and being able to succinctly express data in a graph is essential. "The ability to comfortably work with graphs is a basic skill of the scientist" (Beichner, 750). There have been many studies conducted to explore the depth of knowledge students possess for graph interpretation, and the results have shown that it is lacking across the board.

One study conducted in 1994 on 76 sixth grade students all taught by the same teacher was done to investigate how much students knew about the concepts related to graphing. The purpose of the study was to understand how students interpret graphs, and possible reasons for why there may be errors in the interpretation. The relevant results of this study for this report were that students continued to confuse the axes of the graphs, and that the use of intervals in data can be confusing for students (such as in histograms).[3]

Another study I reviewed, conducted in 1993, tested students' interpretations of kinematic graphs in particular. In fact, this research was done to create a reliable, consistent assessment for testing student understanding of kinematic graphs, which is what today is widely known as the TUG-K (Test of Understanding Graphs - Kinematics)[4]. All the students had been exposed to kinematics at the time they took the test. The mean pre-test test score was 40%, and the difficulties that students faced with this test were generalized to be iconic confusion (believing the graph to be a picture of the situation), slope-height confusion, variable confusion, and others.

Finally I also looked at a set of studies done by five researchers in 2011-2014. There were two studies, the first being about student's understanding of slope in a physics and mathematical context[5], and the second being student reasoning behind graphs in physics, math, and other contexts[6]. In both cases, the students that data was collected from were Croatian, although in the first case the students were high school age, and in the second from the University of Zagreb. However, the results from both were similar in that they indicated that students' weakness when it comes to answering questions with graphs may be related to the questions being asked in a physics context. In the first study, when comparing student answers about slope when asked in a physics context vs a math context, it was found that students got more confused on the physics questions. This could be evidence to support that a lack of mathematical knowledge is not the main difficulty when interpreting graphs. However, the study does also admit that there is also the issue of slope-height confusion and iconic confusion in both contexts. In the follow-up study, the research was focused more generally on graphicacy in different contexts. Once again, it became very apparent that although very similar questions were asked in all three contexts (math, physics, and other), the strategies used were very context-dependent. In other words, the students had varying success using graphs to answer questions when they came from different subjects. When students were presented with the question in the physics context, the preferred method for solving it was to fall back on formulas. The study also reinforced the difficulties that students have with iconic confusion, slope-height confusion, and also difficulties using intervals.

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[3] Building a Theory of Graphicacy: How Do Students Read Graphs? *Friel & Bright*

[4] Testing Student Interpretation of Kinematics Graphs *Beichner*

[5] Comparison of Student Understanding of Line Graph Slope in Physics and Mathematics *Planinic*

[6] Student Reasoning About Graphs in Different Contexts *Planinic*

Overall, there were several issues found from all of these studies. Most prominent among them is student confusion with the derivable elements of a graph, including the slope, area under the curve, and the height at a point. Another is confusion about intervals and how to properly use them in analysis. Finally, and perhaps most importantly, it seems that even if students have the mathematical background to correctly calculate relevant elements of a graph, they often don't feel comfortable finding answers with the graph. The preferred method for solving is to use equations and formulas that are taught in class. While formulas are certainly important for physics, this finding that students rely too heavily on formulas— believing them to be the only way forward— is an issue that should be addressed. Overall, these studies also show that students lack a solid conceptual understanding of why a graph can be used to draw conclusions. This is best expressed in the first study discussed, which remarks that "once an explanation was given, it is clear that many students looked at this graph in ways that provided incorrect reasoning for their answer. In addition, a large number of students provided vague or incomplete responses that seem to say 'you know...the graph says this!' … part of this may reflect the usual emphasis in mathematics on "getting an answer" and seldom on the follow-up questioning that insists on clear explanations from students of why the answers are given." [7] A conceptual understanding of graphs is another issue that should be addressed.

➢ Approach

The question then becomes how to address this lack of understanding of graphicacy in high school and college. The approach was also heavily dependent on the environment at Leominster High School and the classes I taught. After all, students having trouble with graphicacy is not a new issue (Planinic). Beichner suggests that teachers should not assume that students have the knowledge to read graphs, or that they know the vocabulary behind graphicacy. Terms such as slope, change, interval, and the like should be explicitly defined before launching into lessons where graphs are used. Following this, he suggests that teachers have students work with graphs that are not identical to the situation; this will help in resolving some of the iconic confusion. Finally, teachers can give students exercises where they go from motion events to kinematic graphs, and also the other way around. In essence, Beichner says, "Instruction that asks students to predict graph shapes, collect the relevant data, and then compare results to predictions appears

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[7] Building a Theory of Graphicacy: How Do Students Read Graphs? *Friel & Bright*

especially suited to promoting conceptual change" (Beichner, 755). In physics at LHS, the honors students do complete a unit on kinematics graphs, however the general classes usually do not. Thus, for my project, I decided to try to teach the general classes kinematics graphs to begin, and then continue to supplement the course material with graphing methods for other units as well. This was easy to implement as we went through topics such as velocity, acceleration, and projectile motion. It became more of a challenge to teach with graphs when talking about forces and circular motion, but the approach remained relatively unchanged. Many, if not most, of the lesson plans that were designed for the general physics class had some aspect related to graphing, due to the nature of this project. I could not afford to use graphing in as many of the lesson plans for the honors physics classes because of the necessity for Honors to practice word problems with more advanced calculations. However, Honors also tended to learn the concepts much quicker, and so lended itself well to moving past graphing quickly. Incorporating graphing into the lesson plans simply means having students do some form of creation or interpretation of a graph. At the beginning and midpoint of the semester, I had students draw graphs by hand to acquire the skills of scaling and plotting points. Towards the end of the semester, I switched to digital graphing with Google sheets to more quickly graph more complicated data. Throughout the year I asked questions about graphs, including questions about slope, meaning of the graph, how to extract data, and what different equations look like when graphed.

➢ Benefit and Cost

The benefits of this approach to teaching far outweigh the associated costs. Practically, the proposed method of supplementing the normal physics curriculum with additional instruction of graphicacy is easily a viable option in the financial sense. This method of teaching physics imposes no significant financial burden on teachers or schools. Many of the supplies needed (such as rulers and graph paper) are either already a part of the school budget or can be supplied by students. Furthermore, many schools are now starting to supply every student with a personal laptop for classroom use as well, and wherever this occurs it opens the door for graphing with technology. By allocating some classroom time to teaching students how they can use the computational tools available to them, the teacher provides a good starting point into the more technology-based curriculum in college and the workplace.

Even without wide access to computers or the internet, teaching through graphs also provides both student and teacher several benefits. For teachers, simply by weaving graphing into their normal lessons allows graphs to be a powerful tool. Teachers will continue to teach the regular curriculum, but simultaneously train students in graphicacy. Additionally, using graphs as a vehicle for learning grants the educator a lot of potential for new questions. From just one graph, a teacher can ask questions about the slope, scale, area under the curve, physical meaning of changes in the graph, definitions of terms discussed in class, how to draw out equations from simple lines, etc. Moreover, graphs can be easily recycled every year and even for multiple classes in the same year, thereby reducing the amount of annual preparation for an educator. Meanwhile, for students, having the opportunity to learn the skills of graphing early prepares them better for the future. As mentioned before, from my experience and from the experience of other students at WPI, college professors will presume that students know how to read and create graphs and jump right into the content. However, if graphicacy is getting lost in translation between high school and college, then some students may have trouble keeping up. That is why the proposed method is beneficial to students.

This is not to say that there are no costs associated with this methodology. For physics teachers who already have a method that they use, such as having a greater focus on algebra or calculus, then trying to put into practice a greater focus on graphs will require, at best, extra time allotted to rearranging lesson plans, and at worst, a complete shift in pedagogy. Even then, it is not as though teaching with graphs can flow fluidly from the traditional method of teaching physics, because there are certain skills that need to be cultivated in students before they are ready to draw the axes of a graph. Some classroom time is required to at least introduce the terms of graphing, so that students know what the teacher is talking about. And finally, supplementing the curriculum with graphing is not the fastest method for teaching graphing skills. A teacher will maintain the primary purpose in the classroom of teaching physics— not graphing skills. Thus, student learning of purely graphing related concepts will come more slowly than the physics concepts. However, by keeping the two melded together, it prevents students from learning in isolated pockets, allowing them to carry over their knowledge from one subject to another.

➢ Competition

Should this approach to teaching physics work well, then the question becomes whether or not it is a good alternative to other methods of teaching physics. There are several reasons why using this methodology can be competitive in the race to find efficient pedagogies. Some of the benefits of the practice have already been discussed. But in a broader scope, there are other reasons that educators may prefer to supplement their curriculum with graphing. First among these is the fact that graphing involves visuals. As mentioned in the introduction, humans are visual learners first. By ramping up the use of visuals, the physics curriculum may resonate better with more students in the class as opposed to just using words and numbers to describe what is going on. It is inevitable that at some point, every student needs to learn how to work with visuals. So even for the students who prefer to learn in other ways, using graphs can be good practice for future endeavors.

Graphs are also incredibly applicable to a wide variety of fields of study. Every hard science field, including physics, biology, chemistry, engineering, astronomy, mathematics, computer science, geology, etc., all collect and organize data into graphs. If a student wants to pursue a career in any of these fields, having a solid foundation in graphing and how it works will be advantageous. Furthermore, graphs can also be found in fields like medicine, business, and marketing. Doctors and nurses must know how to read graphs of all different types. Businessmen should be able to create graphs to persuade and inform clients. Marketing strategies use graphs all the time to showcase trends and make better decisions. Wherever one finds numbers and data— and even in some places where this is rare— there are bound to be graphs. In the workplace, there is a high demand for people who are proficient in graphicacy. In a 1995 Canadian study, employers were asked what they looked for in employees, and one thing that was mentioned was the ability to "Read, comprehend, and use written materials, including graphs, charts, and displays" (McLaughlin, 4). The larger study mentioned that employers want people who can communicate and continue to learn throughout life. As a final note about using graphicacy to teach, graphs are a good way to accustom students to independent learning. When given a graph, there is no set of instructions to obtaining answers, and so every graph is a new problem. Students have to continue to learn how to read different graphs throughout life.

Methodology

➢ Initial ideas for a project

The first step to any project is identifying a problem. With this project, I wanted to try to improve education in some capacity. Many students at universities have an unspoken understanding: they are not as prepared for college-level courses as they'd like to be. That is why in the early stages of this project, I sent out a brief survey to several student groups. The purpose of this survey was to find out what students wish they learned more about before entering into college, so as to meet the expectations of their professors. The responses to this survey were a bit scattered. However, there were a few points that were repeated by respondents that stuck out, such as vectors and graphing. After conversations with my advisor, the concentration for this project was eventually narrowed down to just focus on graphing. Of course, the main part of the project is the actual teaching practicum, and so it became a study in how to improve and strengthen students' understanding of physics through the focused instruction of graphicacy. By doing this, students would not only learn physics, but hopefully be better prepared to deal with graphs when it came time for college-level courses.

➢ Limitations to research

The main body of this project was the teaching practicum offered through WPI's teacher preparation program. This practicum has a 15 week time frame. I completed the practicum in the fall of 2021, at the same time that high school began. However, I did not officially take over any classroom teaching until two weeks into the practicum, so the pretest was given on September 16 and 17. The posttest was then given on December 16 and 17, exactly 13 weeks later. As the actual teacher for all the classes I took over for, my first priority was always to teach the LHS physics curriculum. I could deviate a little bit, such as when I decided to have a short unit on kinematics graphing with all the general classes even though they don't usually cover graphing on its own. However, I still tried to keep pace with the previous years unit plans.

Since this research was done on human subjects, the main limitations to the research came from the Institutional Research Board (IRB), which works to protect human subjects in clinical trials. The type of research I was conducting was low-risk, but nonetheless certain measures were taken to ensure the safety and comfort of my students. Since I wanted to get as many responses to the test as I could, I wanted to give the test to all of my students. The IRB then required a few things in order to make this requisition possible. First, the test must remain completely anonymous, optional, and cannot count towards a grade. While I can pass the test out to every student, every student has the option to defer from taking the test. In addition, to ensure that all students are still receiving the same education as their peers in other physics classes in the school, the test must remain relatively short; it should be able to be completed in no more than 15 minutes. That way, it is a short break from normal class, and students won't miss an entire day of their normal curriculum. Finally, the IRB had to give the test approval before it could be administered to students. Therefore, I had not been in the classroom or gotten to know the class structure before I had to submit the test for approval.

The final note on limitations on research is that the total number of responses I could've received was bounded by the total number of students I was teaching. This number was further limited by the number of students present on the days that the test was given, and then further by the number of students who elected to take the test, since it was optional. The total number of responses for the pretest was 66, while the total number for the posttest was 62. These totals are split between honors and general physics.

➢ The graphing test

The graphing test that was given to students consisted of three parts: the graphing survey, kinematics graphing, and more complex graphs. Each of these parts were created for a specific purpose. Again, the test used as the pre and post was written before the start of the teaching practicum, so there are some aspects of the test that could be revised to be better. Nonetheless, once the pretest was approved by the IRB, this is the version that had to be used.

The first part of the test is the graphing survey, which is really split into two other sections. The purpose of the survey part is to gauge whether students feel more confident in their graphing ability after being taught physics with a greater focus on graphing. Students are asked eight questions about their confidence in their graphing ability (see Fig. 1). The questions are meant to assess a students' perception of their own ability to make and read graphs. The first four questions only have the options *agree, disagree,* or *neither*, as these questions are more direct and generalized. The second four questions have a Likert scale response, with five options ranging from *Not confident* to *Very confident*. These questions are about specific graphing skills, and a student's confidence in their proficiency in these skills.

After the survey, the next part is for kinematics graphing. The purpose of this part is to assess student understanding of kinematics graphs of position, velocity, and acceleration over time. Due to my prior research, I knew that kinematics graphing skills in physics have been a weak point for students for many years. I wanted to make sure that there was a chance for students to show that they improved on their ability to draw kinematics graphs based on a given scenario. Students are given three scenarios and must draw the position, velocity, and acceleration graph that best fits each scenario. The first scenario is "*A person walking at a constant velocity"*, a simple constant velocity scenario. The second is "*A ball rolling down an inclined plane"*, an example of constant acceleration. The third scenario is "*An arrow shot straight into the air*", which is an example of simple projectile motion. While kinematics graphing was covered as part of the curriculum in all of my classes, I never referred to this test during the lessons. I also never asked students the same questions on any assignments or quizzes. That way, when they took the posttest, it would be a measure of the student's ability to solve a new kinematics graphing problem, instead of one they had explicitly done in class before.

The final part of the test is called "Drawing information from complex graphs". In this context, the term *complex graph* stands for a graph that students are unlikely to have seen before, due to the type or quantity of data it presents, or because the graph is highly conceptualized. The purpose of the complex graphs part is to measure students' ability to interpret unfamiliar and challenging graphs to draw conclusions from them. This part had two graphs: a phase diagram (most commonly seen in chemistry) and a Hertzsprung-Russell (H-R) diagram (most commonly seen in astronomy). The purpose of this part was to assess a student's ability to find answers to questions using only a graph they have never seen before. In this way, students can show that they know how to interpret a graph's axes, find points on the graph, and ultimately have some understanding of the graph. Once again, these graphs were never shown in class, and students were not taught how to read graphs that were similar in nature to these. This forced the students to have to interpret the graphs using only the skills of graphicacy that were taught to them by the integration of graphs into their physics curriculum.

CODE:

Graphing in Physics: Survey

To preserve anonymity, you will create a code to label your paper. This code is only for matching the post test to the pre test, and should not be able to be traced back to you by Mr. Rees. Please put the code on the top of every page.
To create your code, please use three letters and three numbers. The three letters can be anything, such as your mother's initials, the last three letters of your sibling's name, etc. The numbers can also be anything, such as your birthday, etc. Just make it something you can remember so that when you retake this survey at the end of the semester, you can put the same code on the paper.

Also note that this survey is optional to complete, and will only be seen by Mr. Rees to help him with completing his MQP project for college credit.
In addition, ***this will not affect your grade*** for the class in any way whatsoever.

PART 1: Graphing Survey

Circle whether you agree, disagree, or neither with the following statements.

1. I am good at reading graphs.

   Agree Disagree Neither

2. I am good at understanding the data presented in graphs.

   Agree Disagree Neither

3. I am good at creating my own graphs.

   Agree Disagree Neither

4. I am prepared to deal with simple graphs in college/real life.

   Agree Disagree Neither

Circle your degree of confidence with the following statements:

1. If I was given a graph, I would be able to identify the dependent and independent variables.

1 (Not confident)	2	3	4	5 (Very confident)

2. If I was given some simple data, I would be able to plot the data with some graph paper.

1	2	3	4	5
(Not confident)				(Very confident)

3. If a word problem included a graph, I would be able to use the graph to gather some data.

1	2	3	4	5
(Not confident)				(Very confident)

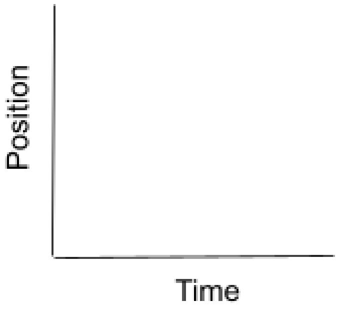
4. If I were asked to find a point on a graph, I would be able to find it.

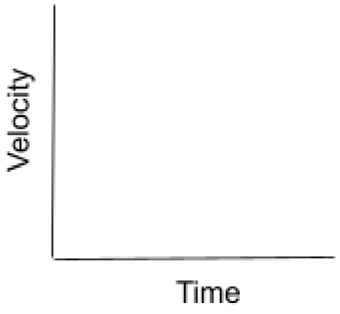
1	2	3	4	5
(Not confident)				(Very confident)

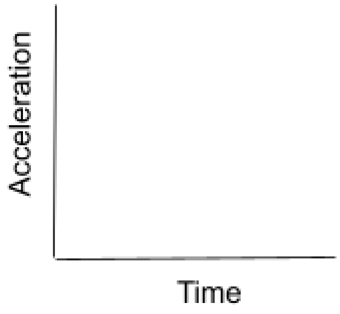
PART 2: Kinematics Graphs

Please give a rough sketch of the following scenarios. Make sure you take note of the axis labels.

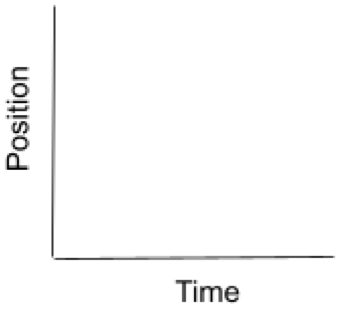
1. A person walking at a constant velocity

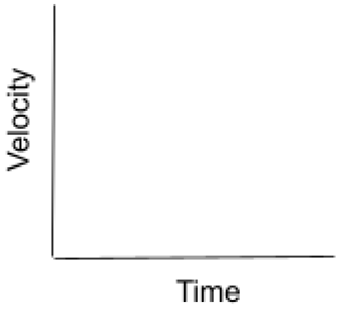


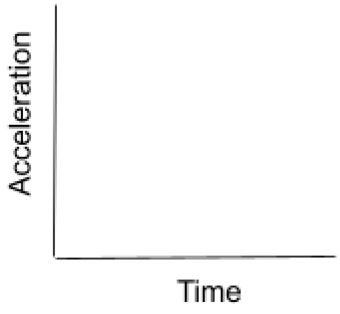




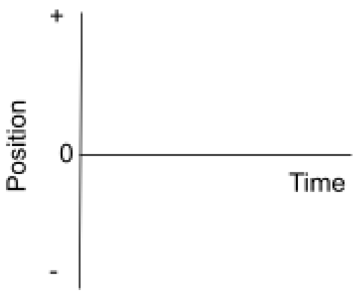
2. A ball rolling down an inclined plane

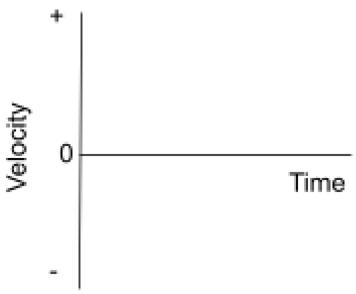


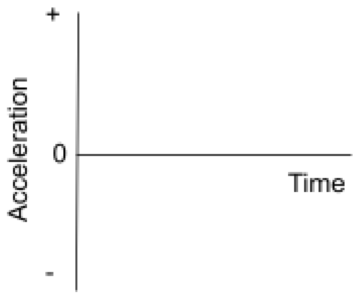




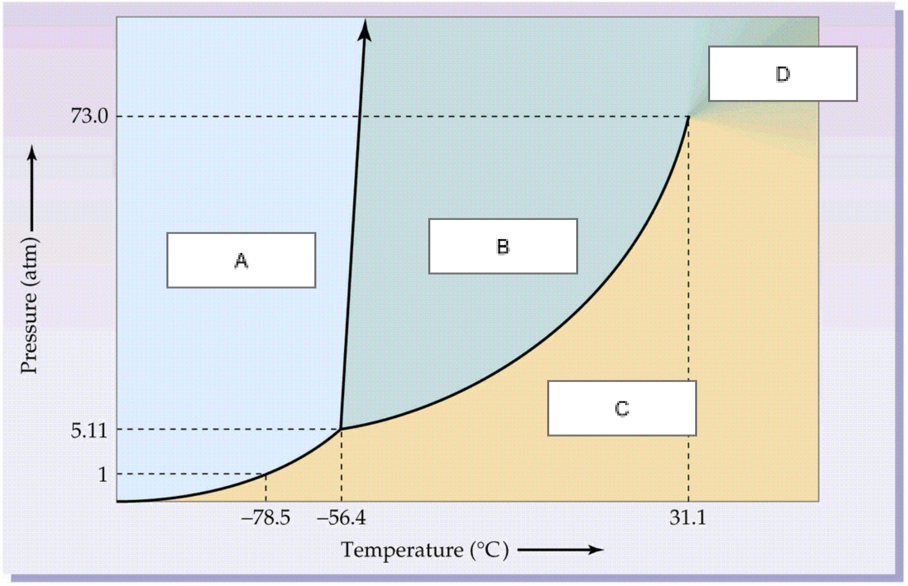
3. An arrow shot straight into the air







PART 3: Drawing information from complex graphs



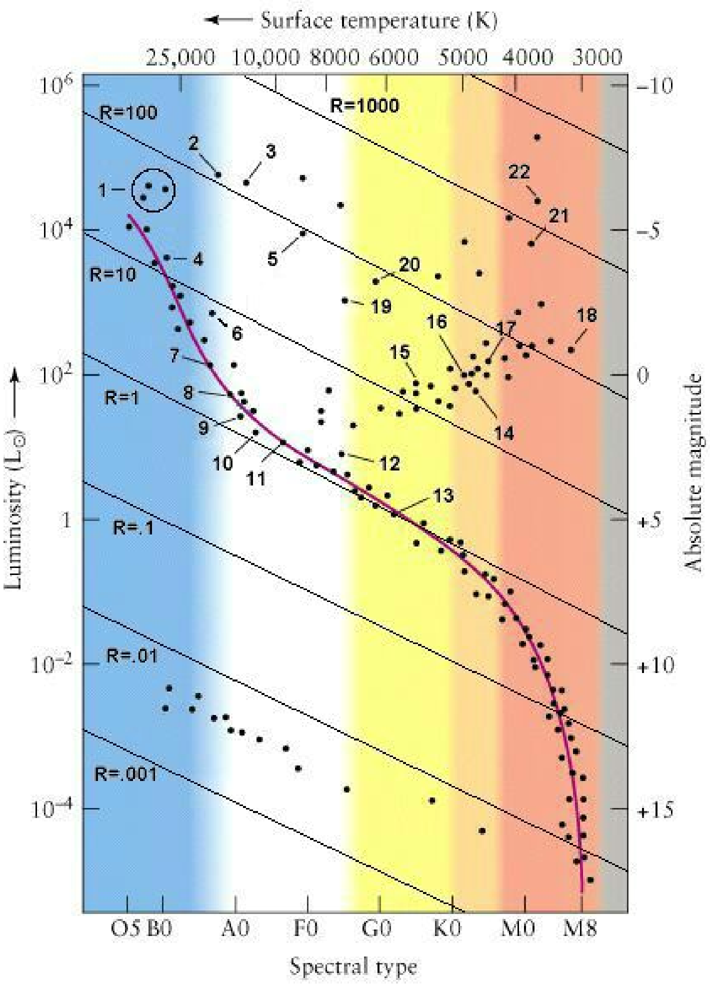
Study the following graphs and answer the questions to the best of your ability.

Increasing the temperature OR decreasing the pressure causes elements to go from solid to liquid to gas. In other words, if an element is at a very high temperature, it's most likely in gas form. But if it's at a very high pressure, it might be in solid form. The opposite is also true; a very low temperature might mean it's a solid, but a very low pressure might mean it's a gas. Using this information, can you infer which state of matter is:

1. A: ___________________
2. B: ___________________ Options: **Solid** **Liquid** **Gas**
3. C: ___________________

Elements in stage D are in two stages of matter at once. Which two stages of matter do you think?

4. ____________ and ____________ .



Note that in this diagram, a more negative absolute magnitude means the star is brighter, and a more positive absolute magnitude means the star is dimmer.

1. Given that the Sun is a Spectral type G0 star, and its luminosity is 1, which number on the graph represents the Sun? _______
2. In general, **the brightest stars are the biggest stars**. White dwarfs are very hot, but very small. Where on the graph would you find white dwarfs? (Circle a general area of the graph)
3. Rigel is a blue supergiant star, and also one of the brightest stars visible in the night sky. Which number on the graph could be Rigel?
   a. 2 b. 11 c. 16 d. 22

2. Betelgeuse is a red supermassive star, and is due to explode in a supernova relatively soon. Which number on the graph could be Betelgeuse?

   a. 10 b. 5 c. 13 d. 22

Figure 1 (above 4 pgs): The survey/test that was administered to all my students as both the pretest and the posttest. It includes three parts: a survey, a kinematics graph part, and a complex graphs part. Also note that this test was translated to both Spanish and Portuguese for English language learners.

➢ Lesson plans

Once the graphing test was made, then the research aspect of the project was underway. However, the actual main bulk of the project still had to be completed, which was the teaching of high school physics to my students through the focused instruction of graphicacy. This was completed during the entire 13 weeks during which I was the teacher-of-record in the classroom. As mentioned, the method of teaching with graphs is simply that: to purposely integrate graphs into the lesson plans as often as possible. While it is not feasible to talk about everything I did in the classroom over the course of the 13 weeks, a brief summary of how the project was carried out will be explored.

a. How a lesson plan is created

It is worthwhile to note the framework that was used to create the lesson plans during this project. As a teacher who is currently progressing through WPI's teacher preparation program, my lesson plans were created with the Understanding by Design (UbD) template established by Grant Wiggins and Jay McTighe. This is a backwards design process where the understandings that students should have by the end of the lesson are the first thing that the teacher considers. This means that every lesson is always learning oriented, not activity oriented. So even though this research requires that the teacher include graphs into the lesson plans, my first priority when writing the plans was always for the learning of the students. This prevents lessons from becoming a collage of different activities with the hope that students will understand the course material by the end of the day. Instead, it forces the teacher to take a step back and reconsider their goal.

UbD lesson plans begin with an overview and motivation for the lesson, and then prompt the teacher to create an essential question. This essential question should be open ended, eliciting the student to have to ask more questions, and can carry over the entire unit. Then teachers can focus more specifically on the objectives that students should strive to achieve by the end of that lesson. These objectives are for the course subject, but there can also be language objectives that can be set forth so as to support English language learners. It is only at this point that the actual itinerary for the lesson is formulated. For this project, this is the stage at which I deliberated how I might teach the objectives I set forth through graphs. When I taught at Leominster High School, I always began my lessons with a Question of the Day (QOTD). This was an informal question posed right after or during attendance. Students did not have to respond to the question in any official format, as it is intended to just break the ice and stimulate students' minds towards learning or exploring. The QOTD was often a chance for me to show students something that interested me. After the QOTD, I moved into the first part of the lesson, which often involved an explanation of the learning activity. Sometimes this is when groups would be announced or formed, if there was group work for that lesson. It is good practice to not have students doing the same activity for too long of a period of time. Most lesson plans included the QOTD, an explanation of the activities, the first activity, some discussion, possibly a second activity, and a final discussion. All of these activities are created keeping in mind the content objectives that were written beforehand.

Going through the question of the day with my mentor teacher, Sarah Friberg. On this day, the question was taken from https://what-if.xkcd.com/ by Randall Munroe.

b. An example of a lesson plan

Figure 2 is an example of a lesson plan that was used in the classroom. This lesson plan is called *Position vs Time "Telephone"*, and it is for the kinematics graphing unit. The goal of the lesson is to wrap up the position vs time graphing section of the unit before beginning to teach velocity vs time graphs. The lesson is meant to be advanced and completed towards the end of the unit, since it places students in the situation where they both perform the motion described by a given graph, and then also try to create another graph based on another group's video. The essential question for this lesson (and also the preceding lessons) is "How do we express an object's physical position over a period of time?” This question is applicable to not just position vs time graphs, but also the derivatives of position, and so it does not have an easy answer. The understanding that I wanted students to fully grasp was that it is possible to express motion using a position vs time graph. Up to this point, we had already been using position vs time graphs, so this lesson was meant as a formative assessment.

Before starting the activity, the QOTD was actually not a question, but a whole-class teacher led examination of a voronoi graph. This was done for two reasons: one, it exposes students to a new type of graph, and continues building skills for graph interpretation. The other reason is because the information in this particular diagram is really surprising, relating to the biomass on Earth. After the brief discussion about the graph, the class was split into groups of 4, and each group was given a different position vs time graph. In their groups, students had to describe the graph using words. They then had to work together to film a 15 second video of one person actually doing the motion as described by their graph, making sure to clearly label the distances on the ground such that they could be seen in the video. Then, groups would trade videos. Using only the other group’s video, students would then attempt to sketch the position vs time graph that the other group was trying to mimic. This is where the “telephone” game analogy comes in. Grading for this assignment was twofold: there was a grade for the accuracy of the video as it related to the group’s given graph, and a separate video for how well the group could sketch the motion of the other group, regardless of accuracy to the original graph.

This lesson plan is very graph-oriented, as it is part of the graphing unit. As a reminder, though, this unit would not typically be covered by the general physics classes, and I decided that it would be worthwhile for the students to explicitly do kinematics graphs as a separate unit. This lesson shows the approach taken to teaching through graphs.

===

Lesson Plan Title: Position vs Time “Telephone”

Teacher’s Name: Simon Rees **Subject/Course:** General physics
Unit: Kinematics Graphs **Grade Level:** 11/12

Overview of and Motivation for Lesson:
Students have been exposed to position vs time graphs a lot so far. Now they get to do a lab where they will do both the movement and the graphing to better connect the two ideas in their mind.

Stage 1-Desired Results

Standard(s):

- HS-PS2-1. Analyze data to support the claim that Newton's second law of motion is a mathematical model describing change in motion (the acceleration) of objects when acted on by a net force.

Aim/Essential Question:

- How do we express an object's physical position over a period of time?

Understanding(s):

Students will understand that . . .

- You can express a situation with motion using a position vs time graph

Content Objectives:	**Language Objectives:**
Students will be able to . . . ● Plot points on a graph ● Analyze a video frame-by-frame ● Plot an object's position over time ● Work collaboratively with other students	ELD Level 1-3 *Students will be able to . . . in English* ● Give the direction of motion (towards, away, neither, from the origin) of a line on the graph ELD Level 4-5 *Students will be able to . . . in English* ● Explain in complete sentences what an object is doing by looking at a position vs time graph

Key Vocabulary

- Position vs time
- Distance
- displacement
- plot
- graph

Stage 2-Assessment Evidence

Performance Task or Key Evidence

- Submitted video from the group
- Completion of the lab worksheet

Key Criteria to measure Performance Task or Key Evidence

- GROUP 1: An accurate sentence describing the initial graph given
- An accurate depiction of the graph in the video
- GROUP 2: An accurate graph of what is shown in the video, regardless of the initial graph
- EXTRA POINTS: two groups whose graphs match up the best in the end

Stage 3- Learning Plan

Learning Activities:

Do Now/Bell Ringer/Opener: 5 min

QOTD: Look at a voronoi diagram about biomass as a class and discuss what it means.

(see bottom for graph)

Learning Activity 1: 10 min

1. Question: has anyone ever played telephone?
   1. If so, have someone explain how it works. If not, the teacher explains.
2. Explain: today we will do a lab just about graphing, and it's sort of like telephone.
   1. It will involve groups, videos, collaboration, and competition. The groups are already made. Every group will be given a position vs time graph.
   2. The group has to analyze the graph, make sure they understand what it means, and then write out what it means in a sentence or two.
   3. They will then make a 15 second video to show the motion in the graph. Make it as accurate as possible. The viewer of the video should be able to see distances marked out on the ground or on the wall.
   4. Then groups will be paired, and the groups must watch the other video and try to recreate the graph that the video is based on.
   5. The first group will be graded based on how accurate the video is according to the original graph. The second group will only be graded based on how good their graph based on the video is. So if the video is totally inaccurate, that's ok— your grade will not suffer.
   6. The two groups that do the best "telephone" with graphs will get +5 points on their graphing quiz sometime next week.

Learning Activity 2: 20-40 min

- Students are free to collaborate with their groups to analyze their given graph, and then create videos based on that graph.
- The teacher will circulate the room (or in this case, also the hallway) to provide support to groups.
- This is a student-centered activity. The goal is to have student groups learn how to work together and understand what the position vs time graph is communicating.

Learning Activity 3: 0-10 min

- If the groups can get through making the video with time to spare in class, then groups can trade videos and try to create the other group's graph based on the video. This is where the "telephone" aspect comes into play.
- If there is not enough time, the class can finish the next time it meets.

Multiple Intelligences Addressed:

☐ Linguistic ☐ **Logical-Math** ☐ Musical ☐Bodily-kinesthetic

☐ Spatial **☐ Interpersonal** **☐Intrapersonal** ☐Naturalistic

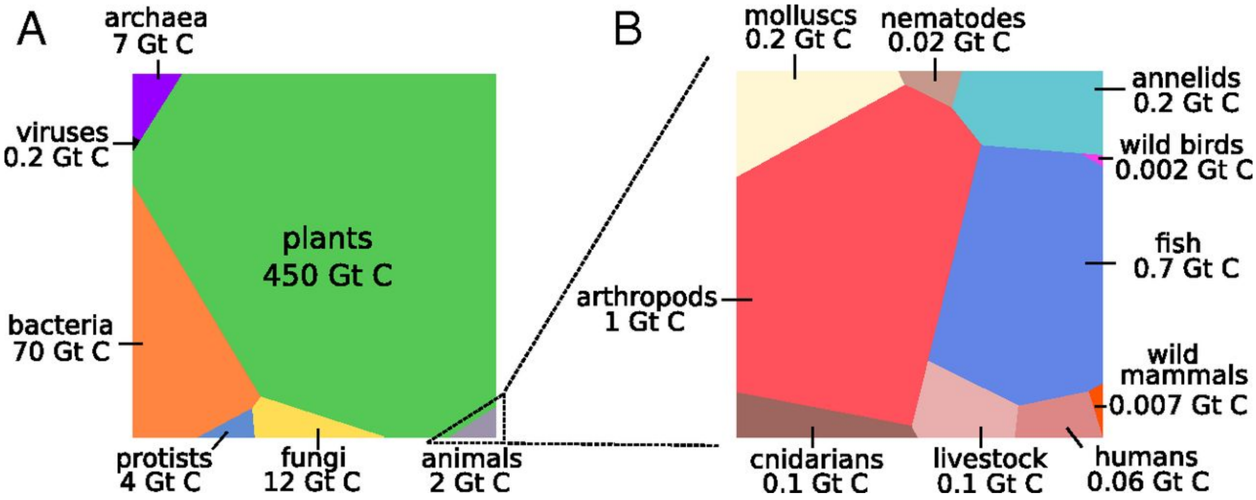
Student Grouping
☐ Whole Class **☐ Small Group** ☐ Pairs ☐ Individual

Instructional Delivery Methods
☐ Teacher Modeling/Demonstration ☐ Lecture **☐ Discussion**
☐ Cooperative Learning ☐ Centers **☐ Problem Solving**
☐ Independent Projects

Materials and Equipment Needed:

- Lab worksheet
- Smartphone with video
- Meter sticks
- Pencils
- Rulers

Adapted from Grant Wiggins and Jay McTighe-*Understanding by Design*



What is this voronoi diagram communicating to you? Does it surprise you?

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Figure 2 (above 4 pgs): The lesson plan for the Position vs Time "Telephone" activity, used in all the general physics classes. This lesson plan is prepared for students to complete position vs time graphs and segway into velocity vs time graphs.

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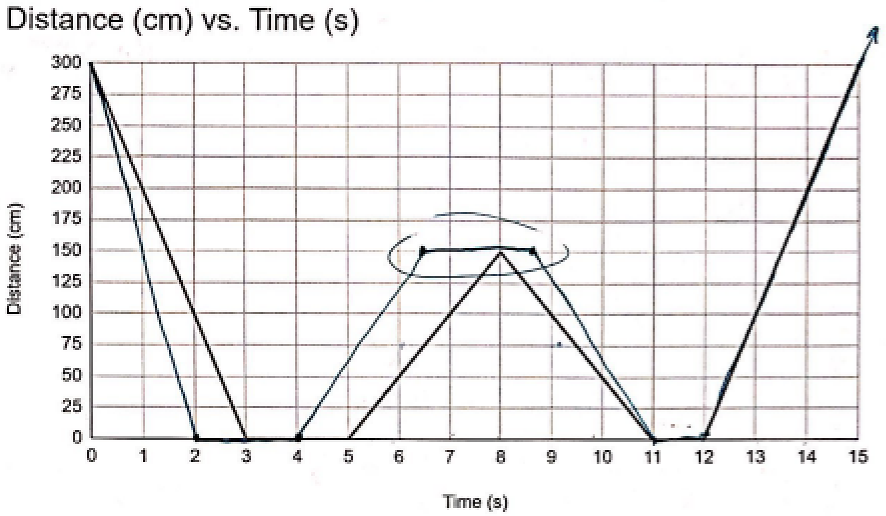
12/15

Graph 2



4. In your groups, you will analyze this position vs time graph of a person walking. As a group, you will write down in a sentence or two what is going on in the graph.

Example (this does not describe your graph): "They walked forward 100 cm in 2 seconds, then stopped for 8 seconds, then walked forwards again another 200 cm in 5 seconds"

They Start at 300cm and walk to 0 in 3 seconds, then stop for 2 seconds, the walk 150 cm in 3 seconds, then walk back to 0 in 3 seconds, pause for 1 seconds, then walk to 300cm in 3 seconds. ✓

5. Once your group has described the graph, you will then create a video of someone in the group acting it out. Make it as accurate as possible! Make sure you are labeling the distances so that you can see them in the video. Your video <u>should be exactly 15 seconds long.</u>

Video was pretty good except for the stop at 150 cm for 2 seconds.

6. Once the video is complete, you will Airdrop/send it to another group, and that group will have to create a graph based on your video.

Recreate other group's graph based on video:
OTHER GROUP'S NUMBER: 4

This is what their video showed

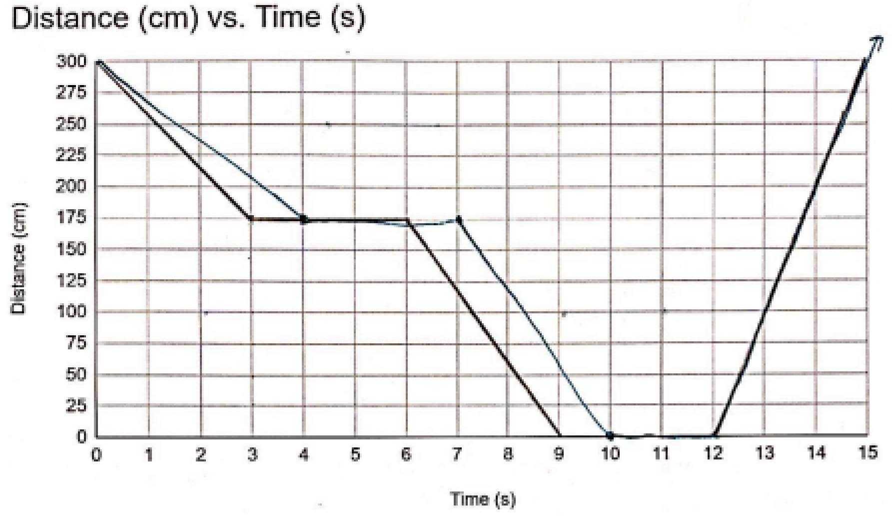


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Figure 3 (above 2 pgs): Real example of student work for the Position vs Time "Telephone" activity. On the first page, the student group was responsible for describing the motion communicated by the position vs. time graph with a sentence or two. They then had to create a video of one member of the group actually following what their graph says is happening. The video is a separate submission for this assignment (not shown here). The second part of the assignment, on page two, is the group sketch based on another group's video submission. Pictured here is both the student work, as well as teacher feedback.

c. Other examples

There are more examples of lesson plans or worksheets which convey the purpose of this project well. All the following examples mentioned— and more— can be found in the Appendix. For example, when I began teaching the general physics classes, I needed to cover constant velocity and acceleration. The *Constant Velocity Lab* is the first lesson I did when I began teaching. It is a hands-on activity meant to demonstrate to students how constant velocity can be described on a position vs time graph by a straight line. It also introduces the concept of velocity being the slope of the line. The *Extension Acceleration Lab* is very similar, and has the same format. This lab was done soon after so students would be able to compare non-constant velocity on a graph (which was especially apparent since the two lab worksheets looked so similar). Students were again asked about slope and what it meant. The *Constant Velocity and Acceleration Lab Debrief* is a final discussion of both labs to help establish the understandings from the two labs, especially relating to the two graphs. The assessment for this unit on velocity and acceleration, *Quiz #1 - 1D Kinematics*, is adapted from prior years' quiz for the unit. I decided to add a section to the quiz on graphing, specifically about interpreting position vs time graphs. This helped me to see where students needed more support going forward.

Following constant velocity and an introduction to acceleration, the classes began to cover free fall and constant acceleration. One lesson I did for this unit was *Graphing Free Fall*, where students just practiced plotting points by hand using data tables that were projected onto the whiteboard. Students had already been taught what free fall was, and this lesson helped to ground student understanding of what the graph for this phenomena looks like for both position vs time and velocity vs time. Correctness of axes labels and scale was accentuated.

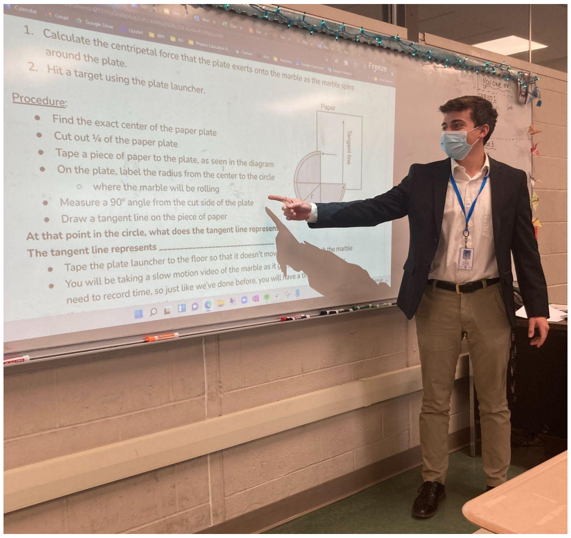
Since the classes had to move onto 2D Kinematics with projectile motion, *2D Vector Lab* was designed to introduce students to vectors and how vector addition is not the same as scalar addition. Students had to physically walk along the vectors that they wrote on their papers, and then find the displacement from start to end. Then students had to do a sort of "graphing" on the worksheet to show what the motion looked like. There were no time axes for this graph, so it was a new type of 1:1 graphing that students had not seen before.

Skipping ahead a few weeks to when the classes were covering Newton's Laws, I included a lesson on graphing when investigating Newton's Second Law. This lesson, *Graphing f=ma*, was very similar to the *Graphing Free Fall* lesson, in that students were tasked in plotting points by hand. However, the expectations were higher for the final graphs, and the data was given out of order to make sure students understand how to correctly create axes and scales. After the graphing was completed, students were asked what the slope represents, since students were creating a graph for the first time where the x-axis was not time. This was meant to overcome misconceptions that all graphs must include time, and also to show how information like the slope can be found by using the axes labels.

Before completing the teaching practicum, I also wanted to leave my students with some experience using the technological graphing resources available to them. *Learning How to Graph with Google Sheets* was the lesson apart from any specific unit that was meant to introduce Google Sheets to students. This was a challenging assignment where students were tasked with exploring the menus and options available in Google Sheets and its chart editor. This was done to give some exposure to the other methods of graphing that students have readily accessible.

During the circular motion unit, the lesson plan *Graphing Centripetal Force on Google Sheets* built on the skills learned from the *Learning How to Graph with Google Sheets*. Students were split into groups, and each group was given a different variable to plot on a graph with force. This was done to illustrate the relationships that each of the variables have on the force an object experiences as it moves in a circle, and how graphs can be used to identify which variables are the most influential.

These lesson plans and worksheets and more are found in the Appendix. The complete database of lessons and worksheets written during the 15 week practicum can can be found at https://drive.google.com/drive/folders/1WwtFQ4nwqT-rrR4VsJe5MsxrBFoMw9Mn?usp=sharing.



In this photo, I am explaining the procedure for a lab.

In this photo, I am reviewing some graphs that can be generated from the equation for centripetal force.

Results

➢ Method of analysis

Since the survey and test were of my own design — with supervision from my supervising practitioner, the IRB, and my advisor — the results were analyzed in a variety of ways to account for the different parts of the test, as well as the flaws in the design which became apparent after the pretest. For the survey part of the test, the percentages of responses will be discussed. This is due to the pre and post test results being too similar, the number of responses too few, and the prevalence of missing responses too great to get significant difference with parametric tests. However, for the assessment part of the test, paired-t tests were used, as well as other methods of comparison. This was possible because there were right and wrong answers, and if a question was left blank it was marked as incorrect.

For the survey part, I will be referring to answers that are positive (i.e. *agree* or a 4-5 on the Likert scale) as answers that signify confidence in graphicacy. Meanwhile, negative answers (i.e. *disagree* or a 1-2 on the Likert scale) will indicate a student is not confident in their ability to graph or read graphs.

➢ Pretest; issues with the test

For the assessment portion of the test, each question had a correct or incorrect answer. However, after grading the pretests, some issues with the test format became apparent, and which caused me to reconsider what to call a correct answer for several questions. With the kinematics graphing part, there could only be one way to grade it since there was hardly any instruction to confuse students. However, for the complex graphs, there were two interesting takeaways.

1. The background information provided for the phase diagram was worded in a confusing way.
2. The test was created in color, but only printed in black and white.

When I wrote the test before officially starting to teach classes, I did not have a good sense of where students stood in their prior knowledge. I also did not want to make the test too easy for fear of the majority of students getting all the answers correct on the pretest, and thereby leaving little room for improvement on the posttest. Therefore, I acted on the side of caution when I created the test. When writing the background information for the phase diagram of water, I tried to give all the information necessary, while also keeping it succinct. What I wrote was, *if an element is at a very high temperature, it's most likely in gas form. But if it's at a very high pressure, it might be in solid form.* As one can see, this sentence emphasizes that high temperatures indicate gasses, and high pressures indicate solids. However, what proceeded from this decision was confusion on the part of the students. This led to most students getting question four of the phase diagram section incorrect. Although the oversight was unfortunate, the responses that students gave for this question proved to give valuable insight into how the mind of a student works when confronted with a test. This will be discussed more in the conclusion.

The other issue with the test was not so much with the way the test was written, but an unforeseen factor which was only realized after the pretest was given. Again, when writing the test, I tried to maintain a certain level of difficulty throughout. Questions three and four of the H-R diagram section of the assessment both referenced the color of the stars in question (Rigel and Betelgeuse). The H-R diagram always appears in color to signify the color of the stars that are plotted on it (although the color of a star is directly related to its surface temperature, so while providing color is not totally necessary, it is much more visually helpful). I had the intention of giving students the graph in color so that they had to use the graph itself to find the answer to the question. However, not until after the tests had been printed and students had taken the test did I remember that color is an important aspect of the graph. Therefore, students were missing a critical piece of background information which was necessary to distinguish the correct answer for questions three and four. Fortunately, both of these questions had another aspect besides color to get the right answer. Question three reads:

- ➢ Rigel is a blue supergiant star, and also one of the brightest stars visible in the night sky. Which number on the graph could be Rigel?
    a. 2 b. 11 c. 16 d. 22

The correct answer is **a**, as the star numbered 2 on the diagram has a very negative absolute magnitude (since negative means it's brighter), and is in the section of the graph that is blue. However, without the information about which section of the graph is blue, then there were two possible answers: **a** or **d**. As it turns out, **d** represents Betelgeuse and is the correct answer for the next question. Question four reads:

- Betelgeuse is a red supermassive star, and is due to explode in a supernova relatively soon. Which number on the graph could be Betelgeuse?
  a. 10 b. 5 c. 13 d. 22

To get this question right, students had to remember the information provided in question two (that the largest stars are the brightest stars), as well as see the color on the graph. Again, without knowing the color, there were two possible correct answers here: **b** and **d**, since both represent very bright stars.

Ultimately, due to the students not having all the necessary information to get the one correct answer for these questions, I awarded a correct answer to students if they circled either of the possible correct answers for each question mentioned above. Even though I noticed what went wrong after grading the pretests, I had to keep the posttests the exact same despite the errors so that the comparison between the pre and post tests could be made. The same criteria for grading was done for both the pre and post test, which is why the comparison is still valid.

➢ Test results

Each of the three parts of the test merit their own analysis. However, as mentioned before, the assessment portion of the test was also graded on an correct/incorrect basis in order to compare raw pretest scores against the posttest scores. There were 17 possible points: one point per graph in the kinematics graphing part for a total of 9 points, and one point per question in the both complex graph sections for a total of 8 points; together the two assessment parts total 17 points. The survey part of the test was not considered for this, since there are no correct or incorrect answers to this part. Overall, the results of the posttest compared to the pretest showed a moderate increase in nearly every section of the test. I analyzed the results for the Honors class apart from the results for the three general physics classes. The analysis was done with a paired-t test.

For the honors class, the pretest (*M* = 6.826, *SD* = 2.565) and posttest (*M* = 8.870, *SD* = 3.314) were compared, and it was found that there was significant difference between the two means (t[22] = -2.13, $p < 0.05$). Similarly, the general classes pretest (*M* = 4.128, *SD* = 2.139) and posttest (*M* = 6.180, *SD* = 2.581) were compared, and it was found that there was significant difference between the two means (t[38] = -4.277, $p < 0.05$). These results show that, on a broad scale, the employed methodology was successful in improving students' knowledge of graphicacy.

The results of the test are further discussed separately for the three parts of the test: survey, kinematics graphing, and complex graphs.

a. Survey Part

i. Honors

Confidence in graphing generally went up by a few percentages for the honors class across the board. One note is that no students chose *1 (not confident)* on either the pretest or the posttest, which suggests that everyone in the Honors class had done some form of graphing and remembered how to do it before taking physics at Leominster High School.

There was, however, some decrease in confidence for particular questions. For example, Question 3, Section 2: *if a word problem included a graph, I would be able to use the graph to gather some data.* For this question, 37.5% of students chose *5 (very confident)* on the pretest, and this dropped to 27.3% on the posttest. This is most likely a reflection of how the honors class struggled with the kinematics graphing unit. During the practicum, Mrs. Friberg noted that the graphing unit is the most difficult unit of the year. While I hadn't officially begun teaching the honors class at this point in the year, I was helping in the classroom and it was clear that many students were struggling. Common issues were recalling how slope and area were related when looking at graphs of positions vs time, velocity vs time, and acceleration vs time. Since the honors class delved much deeper into kinematics graphing than the general classes did, it seems that the honors classes were more realistic with their level of confidence in graphing on the posttest. Nonetheless, when all the responses were averaged, there was a general increase in confidence in graphing ability across the board (see Figures 6 and 7).

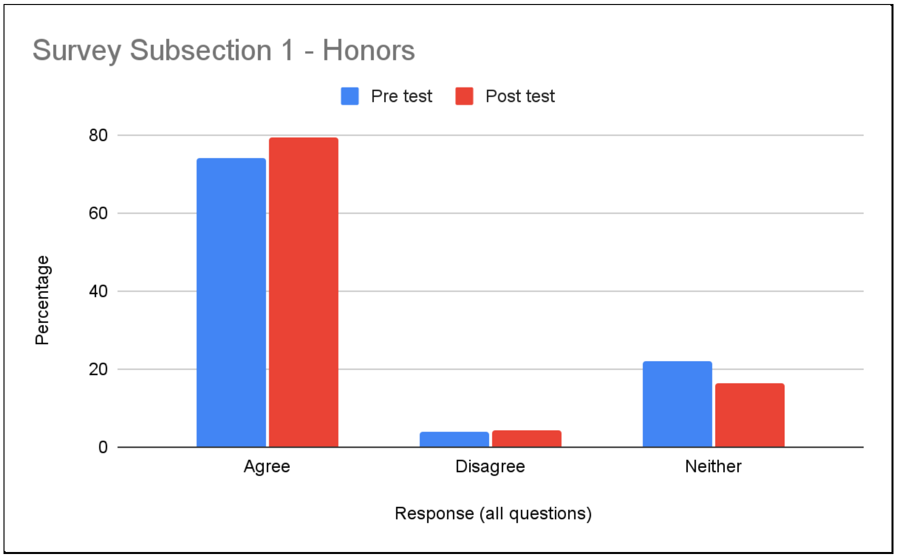


Figure 4: Chart showing the averaged responses of honors students for all questions in Survey Section 1, the very first part of the test. Students' agreement went up slightly in this section, which suggests an increase in confidence.

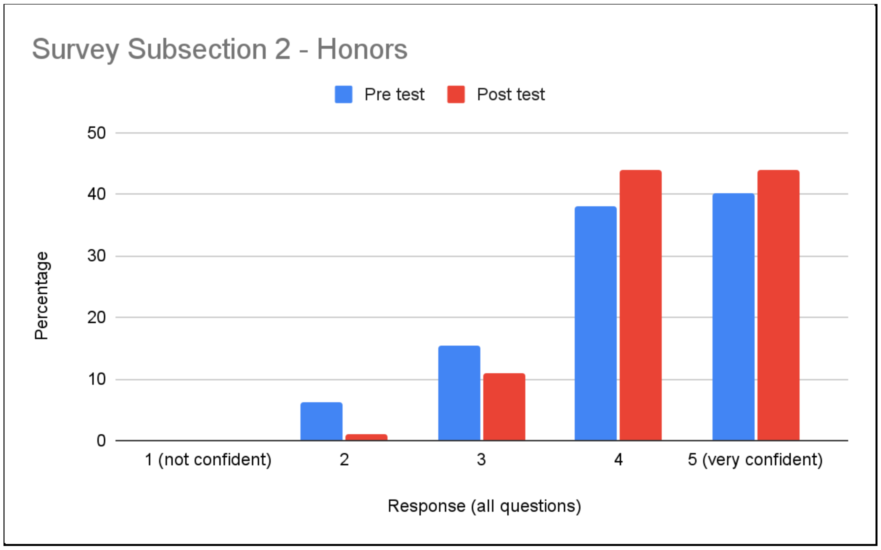


Figure 5: Chart showing the averaged responses of honors students for all questions in Survey Section 2. Students felt markedly more confident on the posttest as compared to the pretest.

ii. General

The general classes showed a more stark increase in confidence on all questions. However, unlike honors, the general classes did have a few responses in both the pretest and the posttest respond with *1 (not confident)* on the second section. Besides that, though, most of the responses suggested equal or higher levels of confidence on the posttest. Some questions of notable increase are section one, question 3, *I am good at creating my own graphs*, and section two, question 2, *if I was given some simple data, I would be able to plot the data with some graph paper.* The former saw a jump from 39% of respondents on the pretest to 69% on the posttest agreeing that they are good at creating graphs, and the latter 15% to 51% saying they were very confident in their ability to plot data. Overall, the general classes felt much more confident by the time they took the posttest.

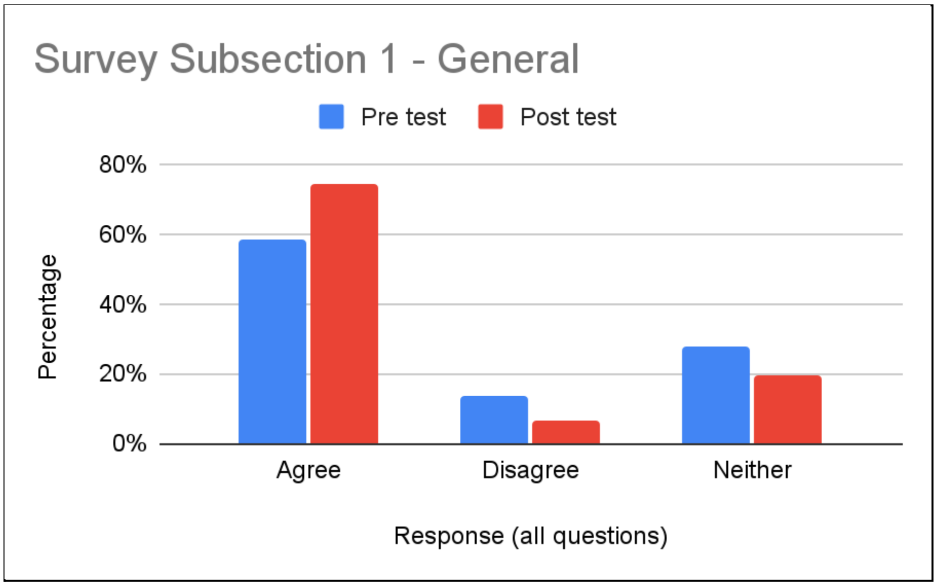


Figure 6: Chart showing the averaged responses of general physics students in all three classes for all questions in Survey Section 1, the very first part of the test. Students' agreement went up by 15% in this section.

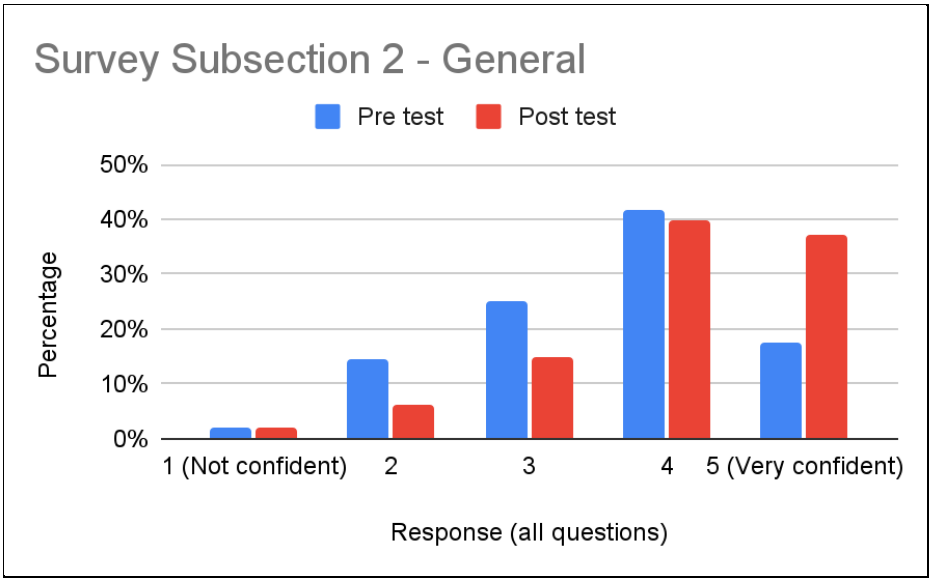


Figure 7: Chart showing the averaged responses of general physics students in all three classes for all questions in Survey Section 2. The percentage of students who felt very confident increased by nearly 20%, even though the responses for "4" was slightly less.

b. Kinematics graphing

Every class that I taught did cover position, velocity, and acceleration vs time graphs as part of the physics curriculum. Each class also worked through problems during the year that were very similar to the questions asked on the graphing test, although not worded exactly the same way. Nevertheless, in both honors and general the kinematics graphing part was difficult for students. Neither group saw a perfect score on this part, although there were some instances where students did get very close. It was clear that students understood position vs time graphs the best out of the three. This is expected, since position vs time graphs follow real life motion the closest, and are easiest to conceptualize. Next came velocity vs time graphs, and then acceleration vs time graphs, which proved to be the most difficult for students. Although the scores— especially for the general classes— were not great, there were differences between pre and post tests. For a few students, the scores were far better on the posttest compared to the pretest.

i. Honors

What is interesting to note about honors is that the class did worse on the position vs time graph for question one on the posttest than on the pretest. The reason for this is unclear. It may be that after going through an intensive unit on graphing, the honors students began to overthink the scenarios and drew the incorrect curve on the posttest. The honors class also did very slightly worse on the velocity vs time graph for question 2 on the posttest. Fortunately, the honors class saw significant improvement everywhere else. For the velocity vs time graph on question two, there were no correct responses on the pretest, but almost 40% of the class got the question correct on the posttest. Surprisingly, there were no correct responses to any of the acceleration vs time graphs on the pretest. Then for acceleration vs time on the posttest, 30% of responses for question 1 were correct, and 52% were correct for question question 2. Unfortunately, still no one got question 3. Nonetheless, this is a great improvement. Overall, the honors class only got 30% of responses correct on three of the nine graphs on the pretest. After the 13 week project, the class was able to get at least 30% of responses correct on seven out of the nine graphs on the posttest.

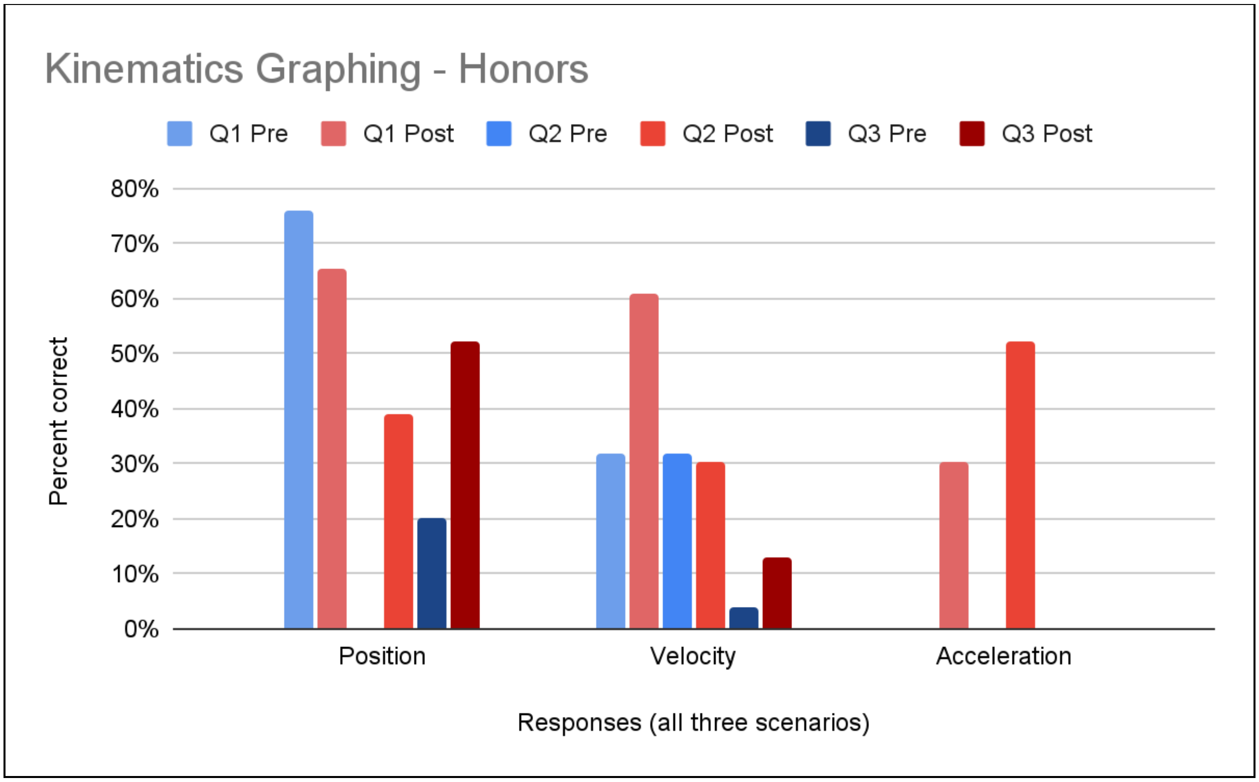


Figure 8: Chart showing the averaged responses of honors physics students for all three questions/scenarios in the Kinematics Graphing part of the test. It is clear to see that posttest scores were far better than the pretest scores. Note that where a bar is missing from the chart, it is because there were no correct responses for that question.

ii. General

Despite the time spent on teaching kinematics graphs as a part of the physics curriculum, the three general classes continued to struggle mightily on kinematics graphs on the posttest. However, there is still improvement that can be seen. In fact, unlike the honors class, the general classes did equally well or better on every single question in this part of the test. And also unlike honors, the general class boasts two students who drew the correct curve for acceleration vs time on the third scenario. Notable increases in scores are in position vs time for question one, which went from 41% to 64% correct from pre to post test, as well as velocity vs time for question one, which went from 17% to 49% correct from pre to post test. Overall, the trend remained exactly the same as for honors, albeit with worse scores. On the pretest, only three of the nine graphs scored above 10% correct, while on the posttest 10% correct was reached by seven of the nine graphs.

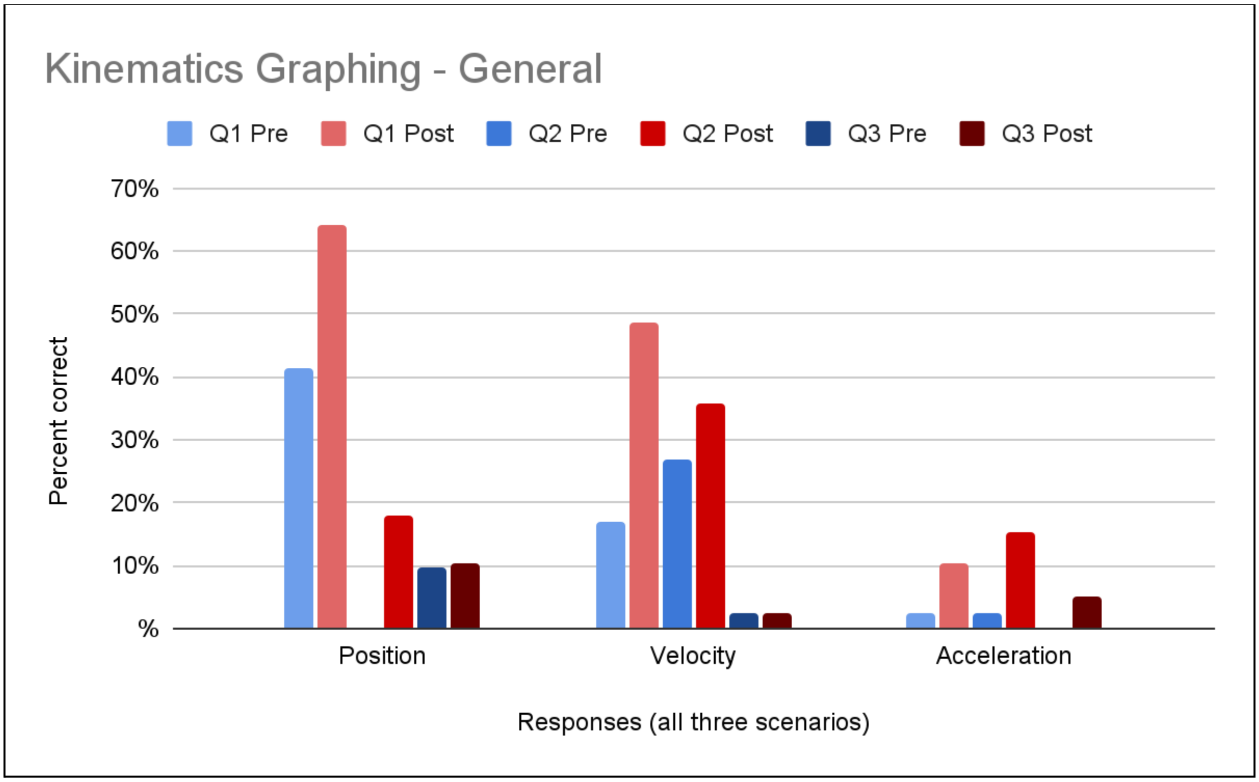


Figure 9: Chart showing the averaged responses of general physics students in all three classes for all three questions/scenarios in the Kinematics Graphing part of the test. While the results are a bit disappointing, there is still an obvious improvement from pretest to posttest. Note that where a bar is missing from the chart, it is because there were no correct responses for that question.

c. Complex Graphs

As previously discussed, the complex graphs part unfortunately had some issues from the start. However, despite these issues, students did remarkably well on this part of the test, even on the pretest. This could be in part because only one of the questions (H-R diagram, question two) was open ended, while the rest were matching or multiple choice. For analysis of this part, one chart was generated comparing the pre and post test scores for the entire complex graphs part of the test for all classes, as well as a breakdown of each of the sections. When averaging the scores for the entire part, there was an increase in the scores on the posttest for every class, with the greatest improvement in period three general physics. This class scored 45% correct on the pretest, but 75% correct on the posttest. Period five general physics also improved significantly, going from 31% to 55% correct from pre to post test. It is unclear why period seven general physics did relatively poorly on the posttest, as period seven was a bright class who throughout the year proved to have original ways of conceptualizing problems. Honors physics did very well on the pretest, and managed to improve for the posttest.

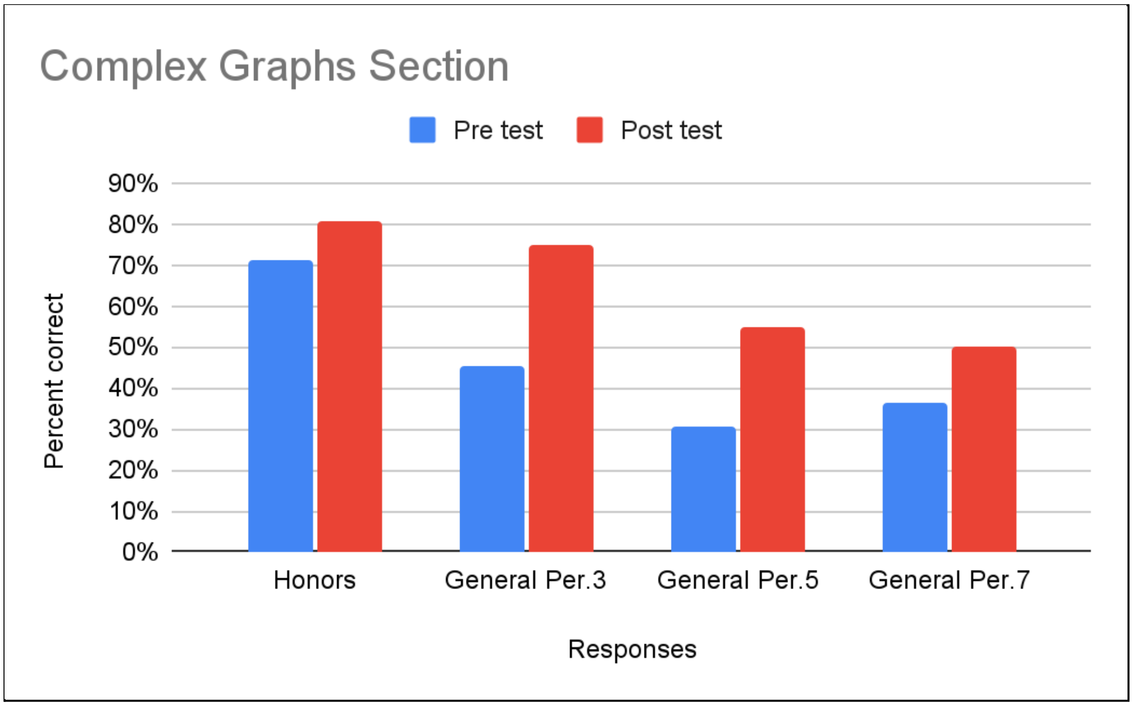


Figure 10: A chart showing the scores on the complex graphing part in all class periods for pre and post tests. It can be seen that in every class, students did better on the posttest.

What is more interesting to note is the breakdown of the sections. For the general classes, the majority of the increase in scores is from the H-R diagram section, while for honors it comes more from the phase diagram. First analyzing the phase diagram section, each class still managed to improve on the posttest, however for general the change is modest. Both period three and period seven saw increases of under five percent, and period five had an increase of ten percent. On the other hand, honors had a nearly 20% jump from pre to post test.

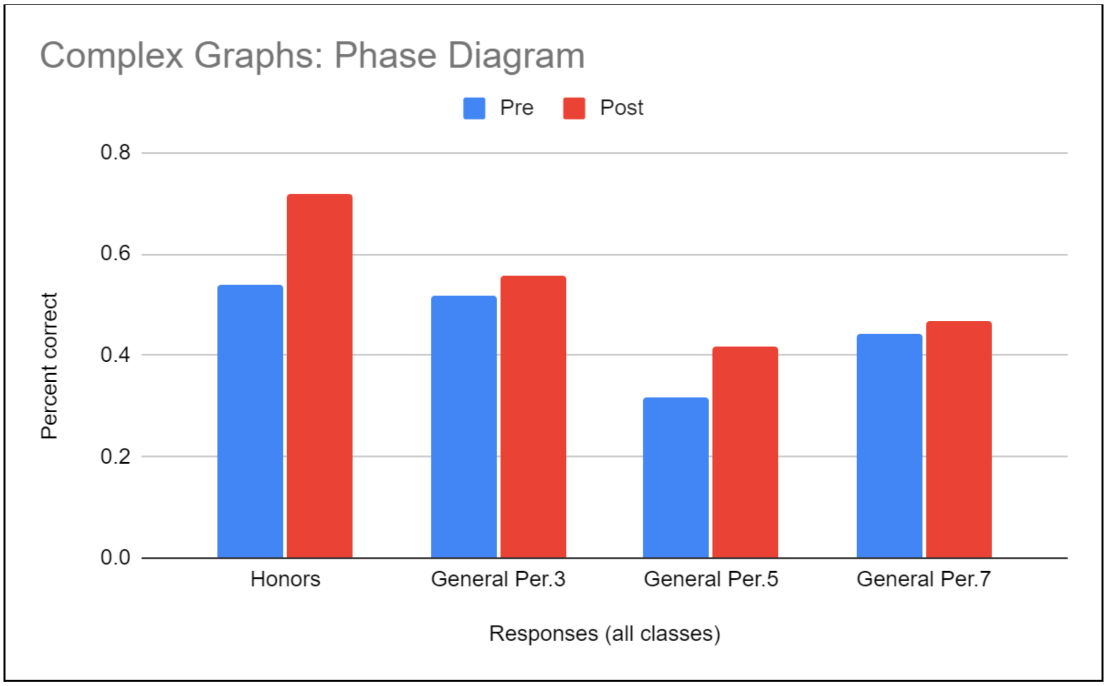


Figure 11: Chart showing the averaged responses of all classes for the Phase Diagram Section for both the pretest and posttest. It can be seen that honors is the class which improved the most from pre to post test, with all the general classes showing a marginal increase of scores.

The opposite of this was true for the H-R diagram section. It was honors that saw a marginal increase in scores, going from 73% to 76%, while all the general physics classes did much better. For example, period three scored just 31% on the pretest, but skyrocketed to 78% on the posttest. Period five and seven also saw great advances, but not to the same extent. What caused this difference in improvements will be discussed in the conclusion.

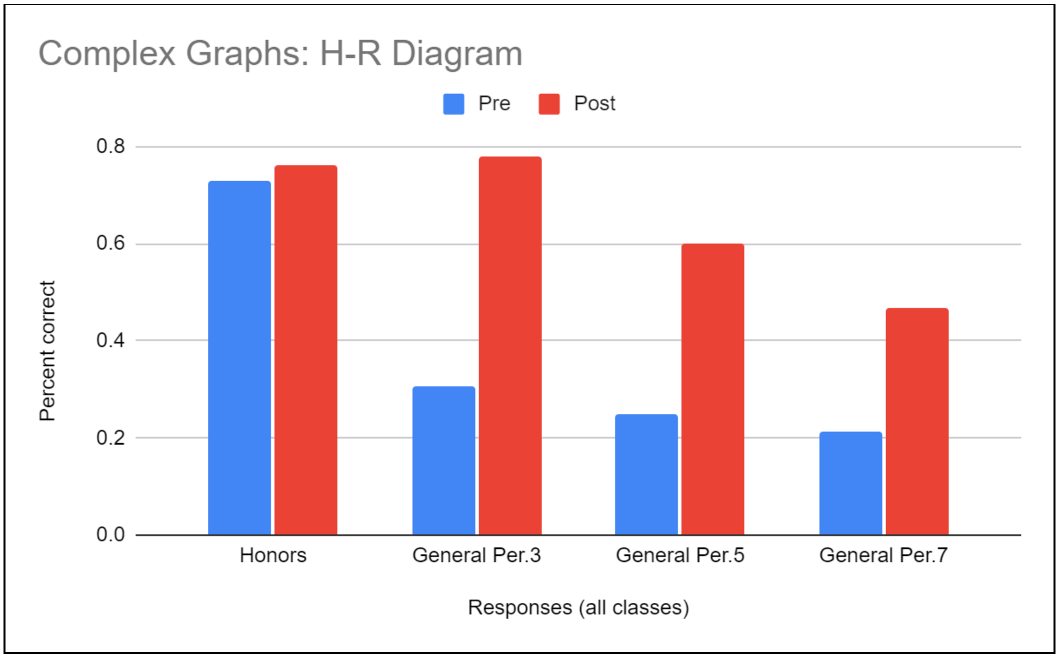


Figure 12: Chart showing the averaged responses of all classes for the H-R Diagram Section for both the pretest and posttest. It can be seen that it is all of the general classes— especially period three— for which there is a huge improvement. Honors also improved, but nowhere nearly as much.

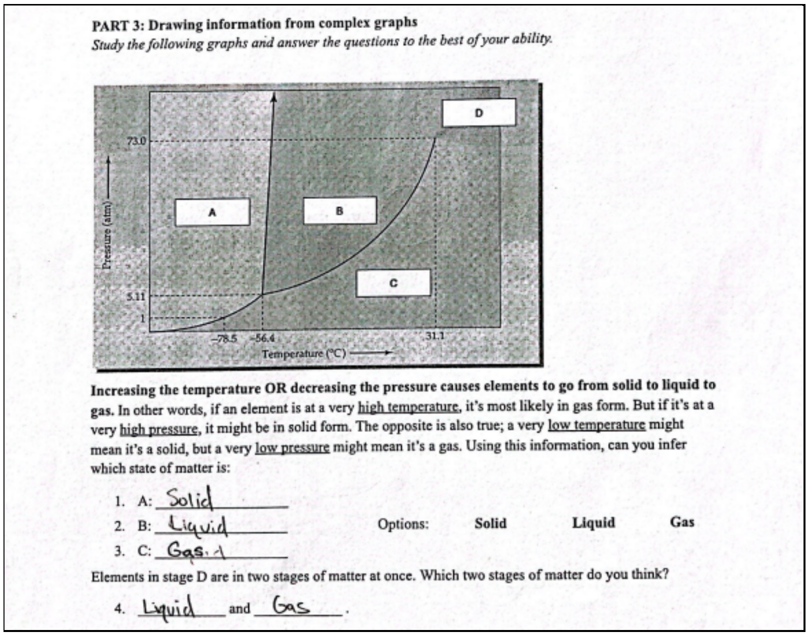
➢ Individual results

While I was not able to have students put their names on their tests, I did have them put anonymous codes that could not be traced back to them by me. In this way, the pressure of performing well on the test because they knew I would be looking at their paper wouldn't be a factor. However, the codes allowed me to correlate a student's pretest to their posttest. Now, I had warned all my classes to remember their codes when I gave the pretest, and encouraged them to write it down somewhere. Of course, being high school students, many of them forgot their codes by the time they took the posttest, so I was not able to match as many pre and post tests as I would have liked. Nonetheless, I did match some, and I will talk about a few interesting results. Recall that these are individual student tests, and are not necessarily a reflection of how the class did overall.

a. Honors

The honors class had several near perfect scores on the assessment portion of the posttest. Of those that did, every one stumbled in the kinematics graphing section.

The first example from honors, Student A, is interesting because of a drastic shift in strengths. On the graded portion of the test, Student A got the same number of total points (9 out of 17) on both the pretest and posttest. On the pretest, this student did excellent on the complex graph part of the test, but did not do well with kinematics. Yet on the posttest, Student A did much better on the kinematics graphs while doing worse with the complex graphs. This was coupled with a decrease in confidence as made evident from the survey part of the test. In the phase diagram section of the test especially, the shift is quite strange. On the pretest, it was clear that Student A understood the question and how to answer it. They answered all of the questions correctly, including question four, which is the one that many students got wrong. Furthermore, on the posttest it’s clear that Student A carefully read the paragraph of background information, as evidenced by the underlining (see Figure 13). Yet, Student A only got one question correct. They even repeated *liquid* as an answer, even though from the context of the question it should have been clear that each letter was matched to a phase of matter. They also fell into the common mistake of answering *gas and solid* as the answer to question 4. One hypothesis as to why the student seemed to not understand the prompt on the posttest when they clearly understood on the pretest is that Student A began to view all graphs through a kinematics lens. Trying to associate the lines with slopes or time may have caused confusion. Another theory is connected to the overreliance on the background information on the posttest. Perhaps on the pretest they used the graph as the primary source of information, and on the posttest they used the paragraph.



PART 3: Drawing information from complex graphs

Study the following graphs and answer the questions to the best of your ability.

Increasing the temperature OR decreasing the pressure causes elements to go from solid to liquid to gas. In other words, if an element is at a very high temperature, it's most likely in gas form. But if it's at a very high pressure, it might be in solid form. The opposite is also true; a very low temperature might mean it's a solid, but a very low pressure might mean it's a gas. Using this information, can you infer which state of matter is:

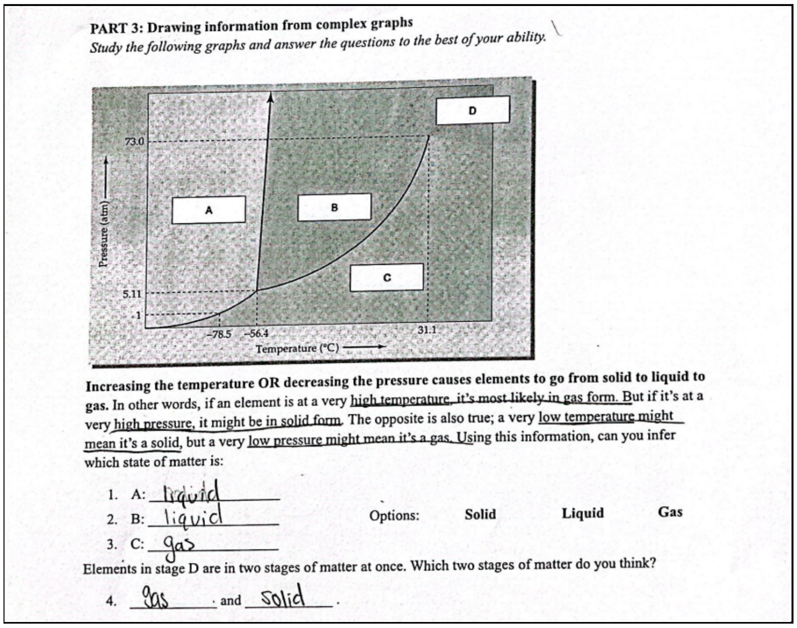
1. A: Solid
2. B: Liquid
3. C: Gas.

Options: **Solid** **Liquid** **Gas**

Elements in stage D are in two stages of matter at once. Which two stages of matter do you think?

4. Liquid and Gas.

Figure 13: Student A's phase diagram section of the pretest. They got all of the answers correct, even question 4, for which many students made a mistake.



PART 3: Drawing information from complex graphs

Study the following graphs and answer the questions to the best of your ability.

Increasing the temperature OR decreasing the pressure causes elements to go from solid to liquid to gas. In other words, if an element is at a very high temperature, it's most likely in gas form. But if it's at a very high pressure, it might be in solid form. The opposite is also true; a very low temperature might mean it's a solid, but a very low pressure might mean it's a gas. Using this information, can you infer which state of matter is:

1. A: liquid
2. B: liquid
3. C: gas

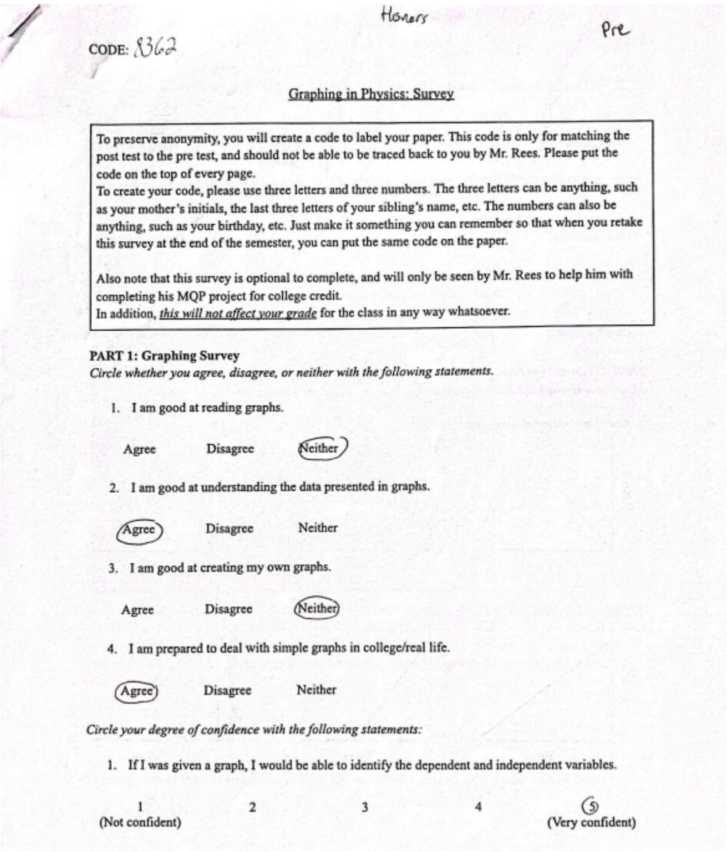
Options: **Solid** **Liquid** **Gas**

Elements in stage D are in two stages of matter at once. Which two stages of matter do you think?

4. gas and solid.

Figure 14: Student A's phase diagram section of the posttest. They only got question two correct, which is unusual since they did perfectly on the pretest.

A good example from the honors showcasing an increase in confidence, a solid conceptual understanding of kinematics graphs, and some improvement on understanding the complex graphs is Student B. In terms of confidence, this student came into the class already confident (see Figure 15), but on the posttest there was a marked increase. On section one, question one, the student changed their answer from *neither* to *agree*. They also circled a 5, meaning very confident, for section two, question three. The only decrease was in section two, question one, which was about identifying independent and dependent variables. This might be due to the activities that the class did to show that anything can be graphed on the axes of a graph, which may have left them a bit confused. The purpose of the activities was to overcome misconceptions that only time can go on the x-axis. Meanwhile, for the assessment portion of the test, this student did above average (8 out of 17) on the pretest and significantly above average (13 out of 17) on the posttest. Most of this increase came from the kinematics graph part, for which the student showed a strong conceptual understanding on the posttest despite getting some questions wrong (see Figure 16). For example, in the second scenario— *a ball rolling down an inclined plane*— the student clearly understood that this was a case of constant acceleration. They drew a correct representation of this situation for the position vs time graph, although they assumed that the bottom of the inclined plane was zero, or the bottom of the plane, instead of the top. From this decision likely came the error in the velocity vs time graph, where they drew the velocity as constantly decreasing instead of constantly increasing. However, it's clear that the conceptual understanding was there. Finally, for the complex graphs part of the test, Student B did perfectly on the H-R diagram section on both the pre and post test, and managed to improve on one question in the phase diagram section (see Figure 16). However, they did not catch the mistake of writing *Solid and Gas* for question four on the posttest. However, as mentioned previously, this may have been a result of the way this background information was phrased.



Honors

Pre

CODE: 8362

Graphing in Physics: Survey

To preserve anonymity, you will create a code to label your paper. This code is only for matching the post test to the pre test, and should not be able to be traced back to you by Mr. Rees. Please put the code on the top of every page.
To create your code, please use three letters and three numbers. The three letters can be anything, such as your mother's initials, the last three letters of your sibling's name, etc. The numbers can also be anything, such as your birthday, etc. Just make it something you can remember so that when you retake this survey at the end of the semester, you can put the same code on the paper.

Also note that this survey is optional to complete, and will only be seen by Mr. Rees to help him with completing his MQP project for college credit.
In addition, *this will not affect your grade* for the class in any way whatsoever.

PART 1: Graphing Survey
Circle whether you agree, disagree, or neither with the following statements.

1. I am good at reading graphs.

Agree Disagree [✓ Neither]

2. I am good at understanding the data presented in graphs.

[✓ Agree] Disagree Neither

3. I am good at creating my own graphs.

Agree Disagree [✓ Neither]

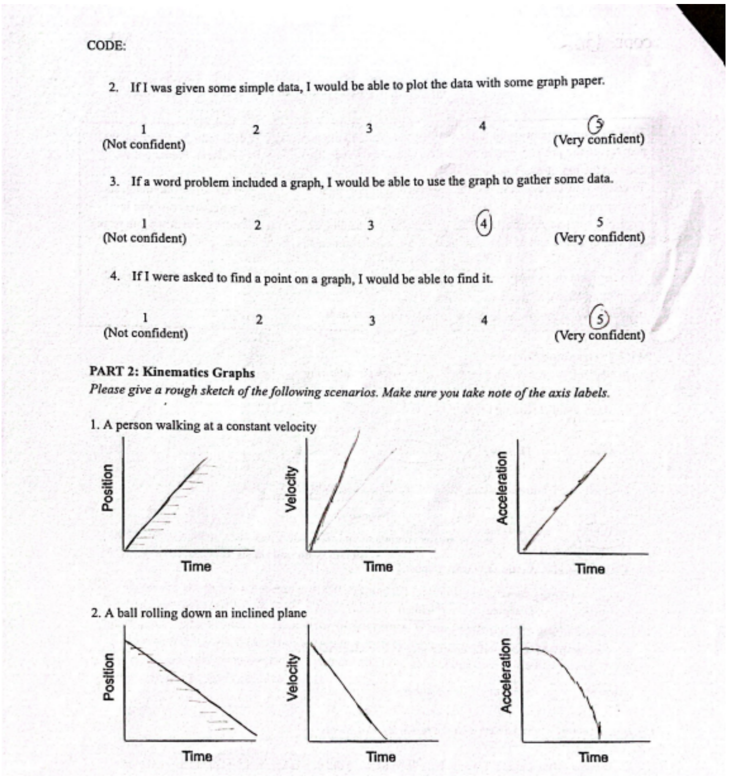
4. I am prepared to deal with simple graphs in college/real life.

[✓ Agree] Disagree Neither

Circle your degree of confidence with the following statements:

1. If I was given a graph, I would be able to identify the dependent and independent variables.

1 (Not confident) 2 3 4 [✓ 5] (Very confident)



CODE:

2. If I was given some simple data, I would be able to plot the data with some graph paper.

1 (Not confident) 2 3 4 [✓ 5] (Very confident)

3. If a word problem included a graph, I would be able to use the graph to gather some data.

1 (Not confident) 2 3 [✓ 4] 5 (Very confident)

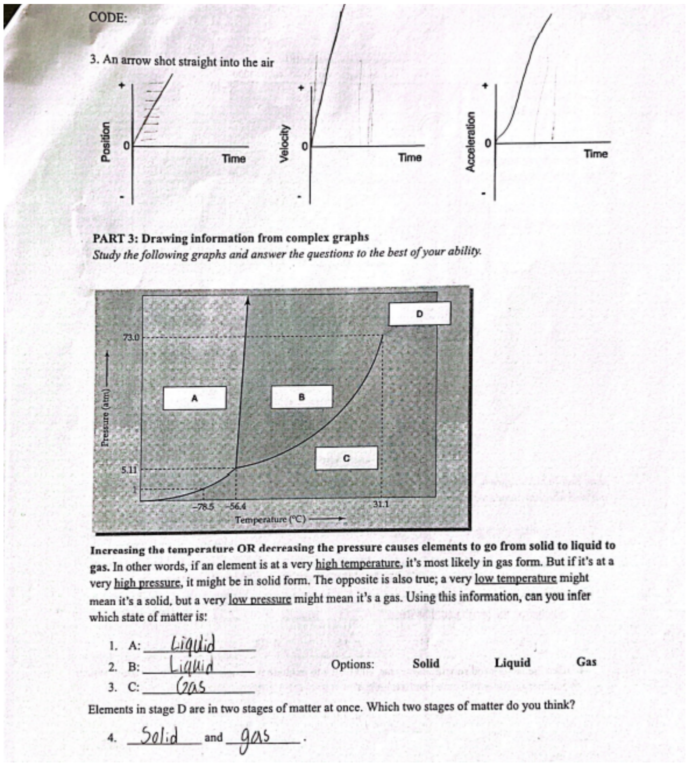
4. If I were asked to find a point on a graph, I would be able to find it.

1 (Not confident) 2 3 4 [✓ 5] (Very confident)

PART 2: Kinematics Graphs
Please give a rough sketch of the following scenarios. Make sure you take note of the axis labels.

1. A person walking at a constant velocity

2. A ball rolling down an inclined plane



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3. An arrow shot straight into the air

PART 3: Drawing information from complex graphs

Study the following graphs and answer the questions to the best of your ability.

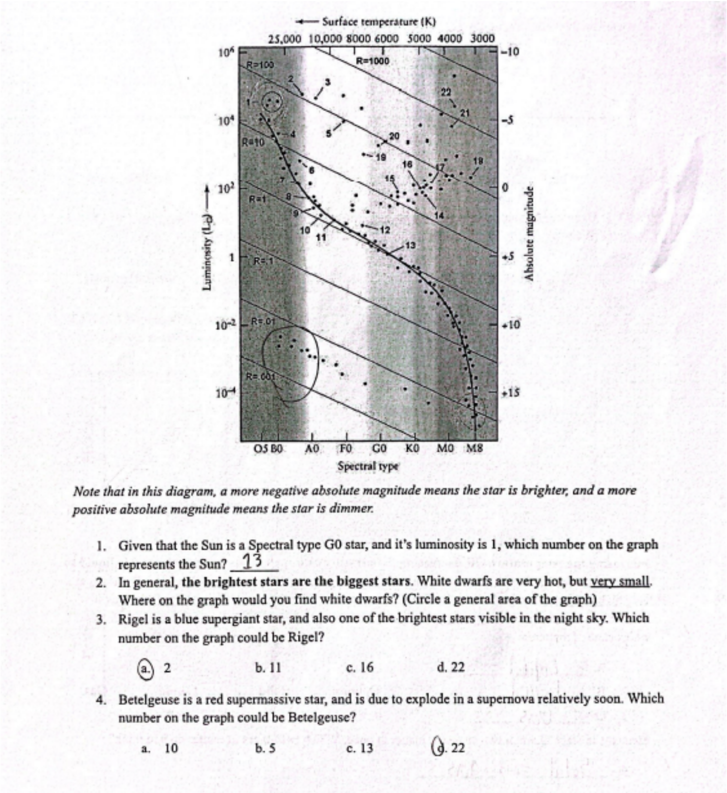
Increasing the temperature OR decreasing the pressure causes elements to go from solid to liquid to gas. In other words, if an element is at a very high temperature, it's most likely in gas form. But if it's at a very high pressure, it might be in solid form. The opposite is also true; a very low temperature might mean it's a solid, but a very low pressure might mean it's a gas. Using this information, can you infer which state of matter is:

1. A: Liquid
2. B: Liquid
3. C: Gas

Options: **Solid** **Liquid** **Gas**

Elements in stage D are in two stages of matter at once. Which two stages of matter do you think?

4. Solid and gas.



Note that in this diagram, a more negative absolute magnitude means the star is brighter, and a more positive absolute magnitude means the star is dimmer.

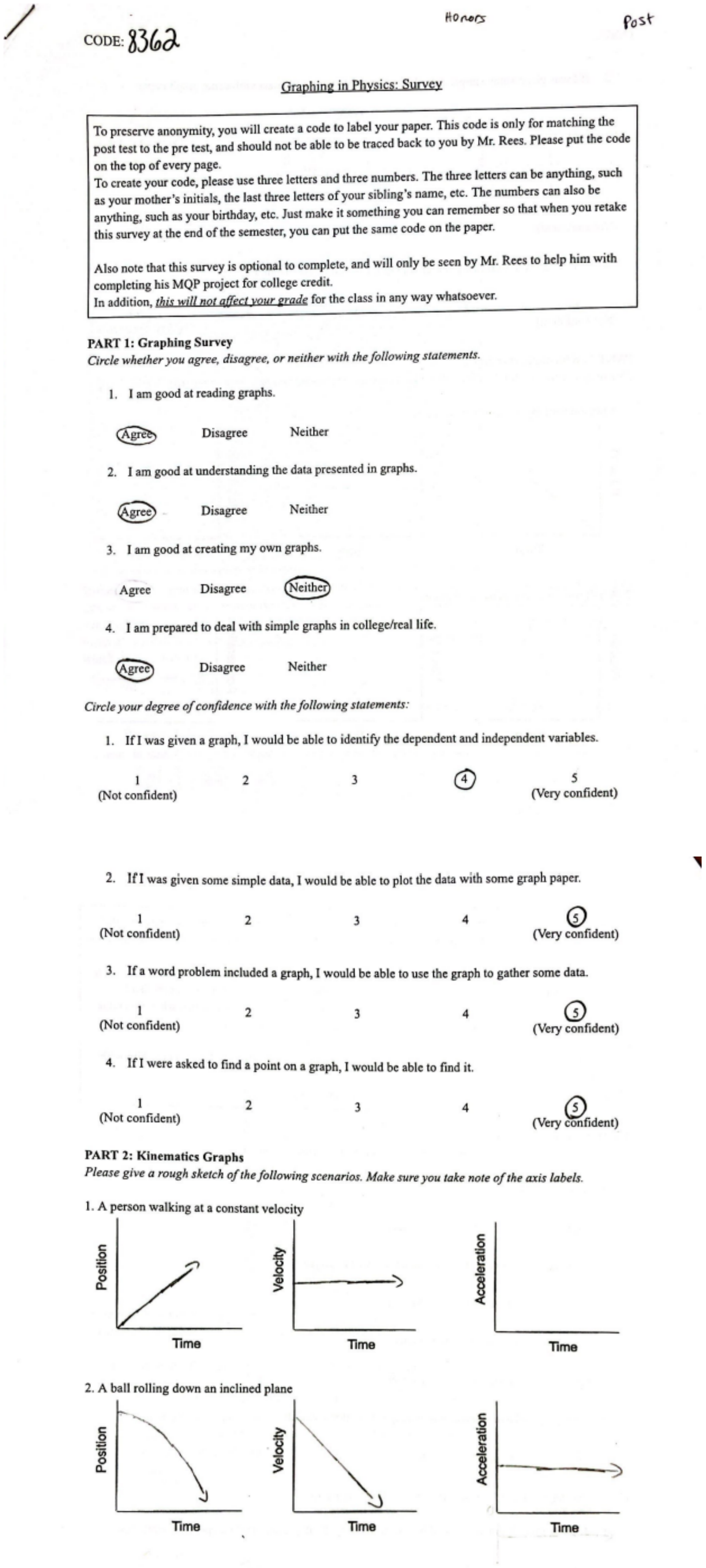
1. Given that the Sun is a Spectral type G0 star, and it's luminosity is 1, which number on the graph represents the Sun? 13
2. In general, **the brightest stars are the biggest stars.** White dwarfs are very hot, but very small. Where on the graph would you find white dwarfs? (Circle a general area of the graph)
3. Rigel is a blue supergiant star, and also one of the brightest stars visible in the night sky. Which number on the graph could be Rigel?

   [✓ a. 2] b. 11 c. 16 d. 22

4. Betelgeuse is a red supermassive star, and is due to explode in a supernova relatively soon. Which number on the graph could be Betelgeuse?

   a. 10 b. 5 c. 13 [✓ d. 22]

Figure 15 (above 2 pgs): Pretest from Student B. They were often confused (and most likely guessing) on the kinematics graphs, however they did well on the complex graphs part.



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Honors Post

CODE: 8362

Graphing in Physics: Survey

To preserve anonymity, you will create a code to label your paper. This code is only for matching the post test to the pre test, and should not be able to be traced back to you by Mr. Rees. Please put the code on the top of every page.
To create your code, please use three letters and three numbers. The three letters can be anything, such as your mother's initials, the last three letters of your sibling's name, etc. The numbers can also be anything, such as your birthday, etc. Just make it something you can remember so that when you retake this survey at the end of the semester, you can put the same code on the paper.

Also note that this survey is optional to complete, and will only be seen by Mr. Rees to help him with completing his MQP project for college credit.
In addition, *this will not affect your grade* for the class in any way whatsoever.

PART 1: Graphing Survey
Circle whether you agree, disagree, or neither with the following statements.

1. I am good at reading graphs.

[✓ Agree] Disagree Neither

2. I am good at understanding the data presented in graphs.

[✓ Agree] Disagree Neither

3. I am good at creating my own graphs.

Agree Disagree [✓ Neither]

4. I am prepared to deal with simple graphs in college/real life.

[✓ Agree] Disagree Neither

Circle your degree of confidence with the following statements:

1. If I was given a graph, I would be able to identify the dependent and independent variables.

1 (Not confident) 2 3 [✓ 4] 5 (Very confident)

2. If I was given some simple data, I would be able to plot the data with some graph paper.

1 (Not confident) 2 3 4 [✓ 5] (Very confident)

3. If a word problem included a graph, I would be able to use the graph to gather some data.

1 (Not confident) 2 3 4 [✓ 5] (Very confident)

4. If I were asked to find a point on a graph, I would be able to find it.

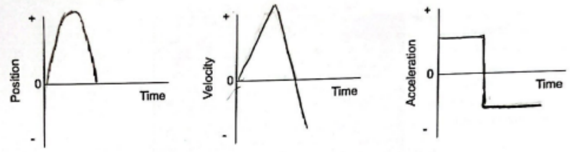
1 (Not confident) 2 3 4 [✓ 5] (Very confident)

PART 2: Kinematics Graphs
Please give a rough sketch of the following scenarios. Make sure you take note of the axis labels.

1. A person walking at a constant velocity

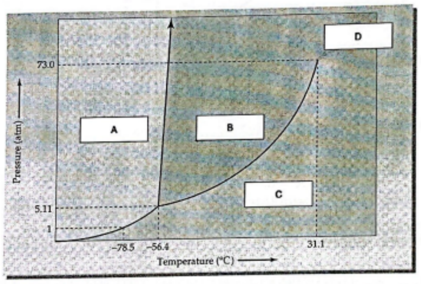
2. A ball rolling down an inclined plane

3. An arrow shot straight into the air



PART 3: Drawing information from complex graphs

Study the following graphs and answer the questions to the best of your ability.



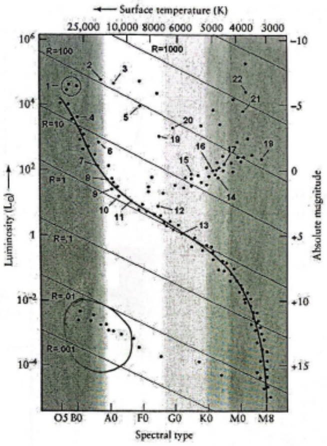
Increasing the temperature OR decreasing the pressure causes elements to go from solid to liquid to gas. In other words, if an element is at a very high temperature, it's most likely in gas form. But if it's at a very high pressure, it might be in solid form. The opposite is also true; a very low temperature might mean it's a solid, but a very low pressure might mean it's a gas. Using this information, can you infer which state of matter is:

1. A: Solid
2. B: Liquid
3. C: Gas

Options: **Solid** **Liquid** **Gas**

Elements in stage D are in two stages of matter at once. Which two stages of matter do you think?

4. Sol:d and Gas.



Note that in this diagram, a more negative absolute magnitude means the star is brighter, and a more positive absolute magnitude means the star is dimmer.

1. Given that the Sun is a Spectral type G0 star, and it's luminosity is 1, which number on the graph represents the Sun? 13
2. In general, **the brightest stars are the biggest stars**. White dwarfs are very hot, but very small. Where on the graph would you find white dwarfs? (Circle a general area of the graph)
3. Rigel is a blue supergiant star, and also one of the brightest stars visible in the night sky. Which number on the graph could be Rigel?

   [✓ a. 2] b. 11 c. 16 d. 22

4. Betelgeuse is a red supermassive star, and is due to explode in a supernova relatively soon. Which number on the graph could be Betelgeuse?

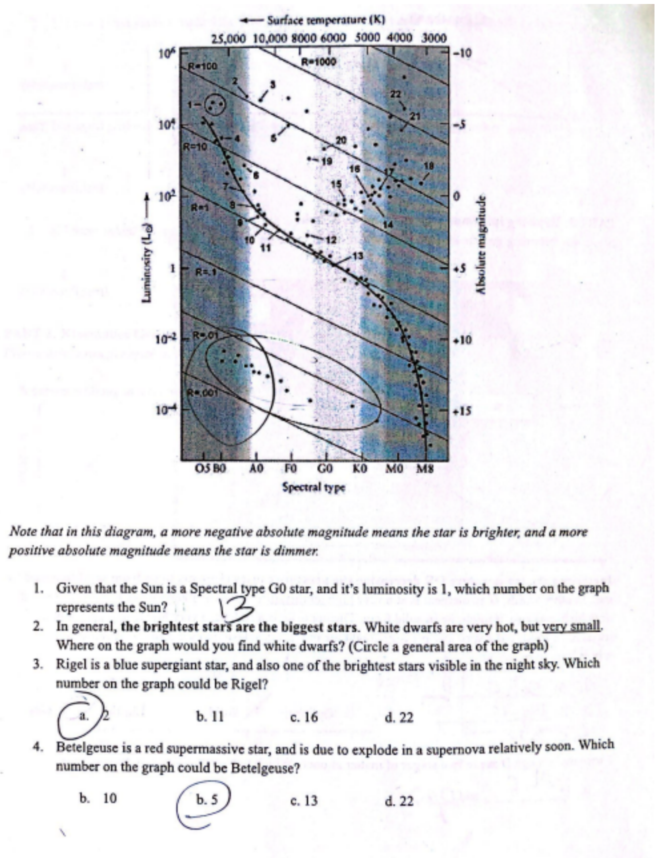
   a. 10 b. 5 c. 13 [✓ d. 22]

Figure 16 (above 2 pgs): Posttest from Student B. They did very well on the kinematics graphs, but made the same mistake for the phase diagram section (question four) as in the pretest.

b. General

For the general physics students, the trend was quite consistent across all three of the classes. For the most part, even though many of them felt relatively confident in their ability, students did poorly on the pretest; some students left entire parts blank. However, on the posttest, almost every student at least attempted every part of the test. Even if they did not do well, there was clearly comprehension of what the question asked and how to approach the graphs.

One example is Student C from Period 3. On the pretest, this student did not feel overly confident, had no experience with kinematics graphs, and didn't even attempt the H-R diagram section of the complex graphs part. On the posttest, their confidence went up a little bit, had a far better conceptual understanding of kinematics graphs (especially acceleration vs time graphs), and actually attempted and correctly answered the entire H-R diagram section.



Note that in this diagram, a more negative absolute magnitude means the star is brighter, and a more positive absolute magnitude means the star is dimmer.

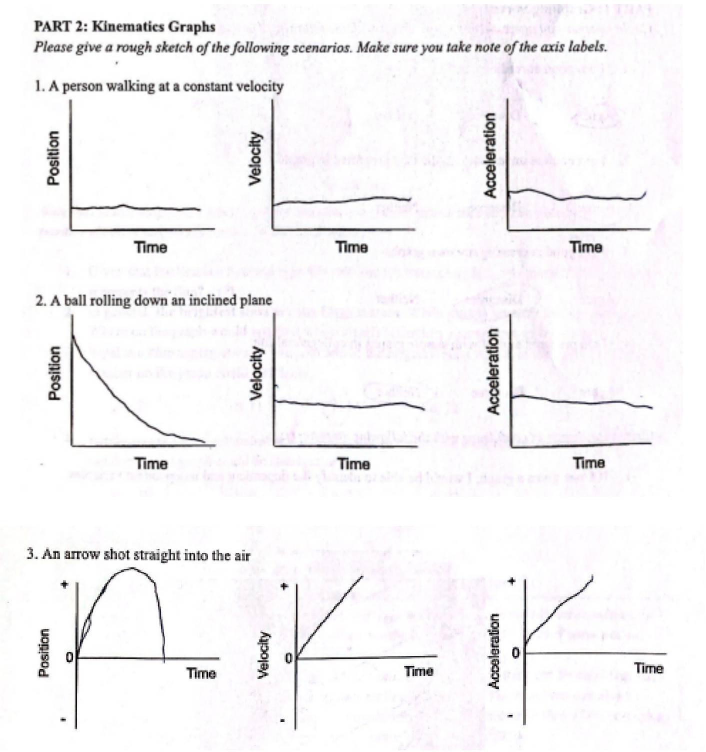
1. Given that the Sun is a Spectral type G0 star, and it's luminosity is 1, which number on the graph represents the Sun? 13
2. In general, **the brightest stars are the biggest stars**. White dwarfs are very hot, but <u>very small</u>. Where on the graph would you find white dwarfs? (Circle a general area of the graph)
3. Rigel is a blue supergiant star, and also one of the brightest stars visible in the night sky. Which number on the graph could be Rigel?

   [✓ a. 2] b. 11 c. 16 d. 22
4. Betelgeuse is a red supermassive star, and is due to explode in a supernova relatively soon. Which number on the graph could be Betelgeuse?

   b. 10 [✓ b. 5] c. 13 d. 22

Figure 17: Student C's H-R diagram section of the posttest. On the pretest, this student left this entire section blank. But on the posttest, they put an acceptable answer to every question.

Another example is Student D from Period 5. This student is a good example of someone who has a decent grasp of kinematics graphs, but who still got confused and answered incorrectly. For the survey section of the test, Student D showed some increases in confidence, while also answering with a more realistic outlook on their graphicacy skills. There wasn't much change between pre and post tests for the complex graph part. However, for the kinematics graphs, this student exhibited a significantly better understanding (see Figure 18). On the posttest, they answered scenario one perfectly, demonstrating that they at least understood constant velocity graphically. In scenario two, none of the responses were correct. However, Student D knew that for a ball rolling down an inclined plane, the position vs time graph should not be a straight line, as they initially responded and then erased. In scenario three it can be seen that the student knew how projectile motion looked graphically for position vs time. They then mixed up a constantly increasing velocity with a constantly decreasing velocity, but remembered that the acceleration was a constant negative value. These responses, though not all correct, reveal a decent conceptual understanding of how kinematics graphs are graphed.



PART 2: Kinematics Graphs

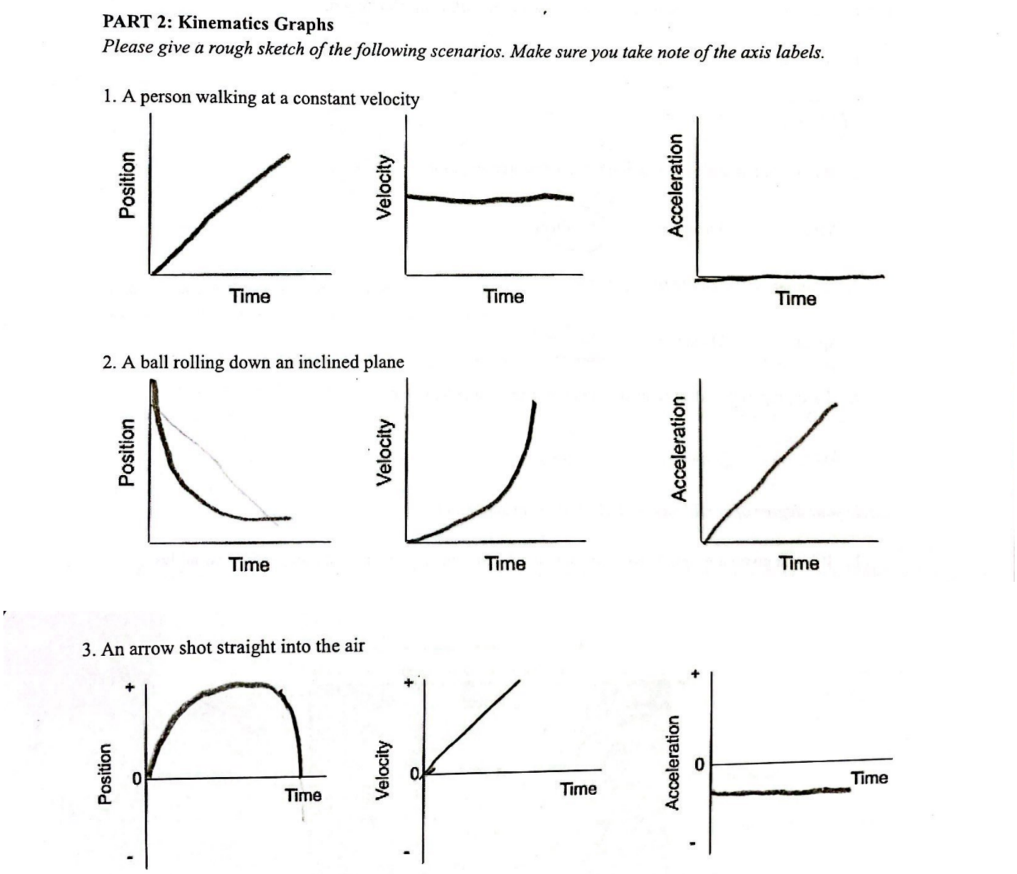
Please give a rough sketch of the following scenarios. Make sure you take note of the axis labels.

1. A person walking at a constant velocity

2. A ball rolling down an inclined plane

3. An arrow shot straight into the air

Figure 18: Student D's kinematics part of the pretest, where only two sketches are correct (scenario one, velocity; scenario two, acceleration).



PART 2: Kinematics Graphs

Please give a rough sketch of the following scenarios. Make sure you take note of the axis labels.

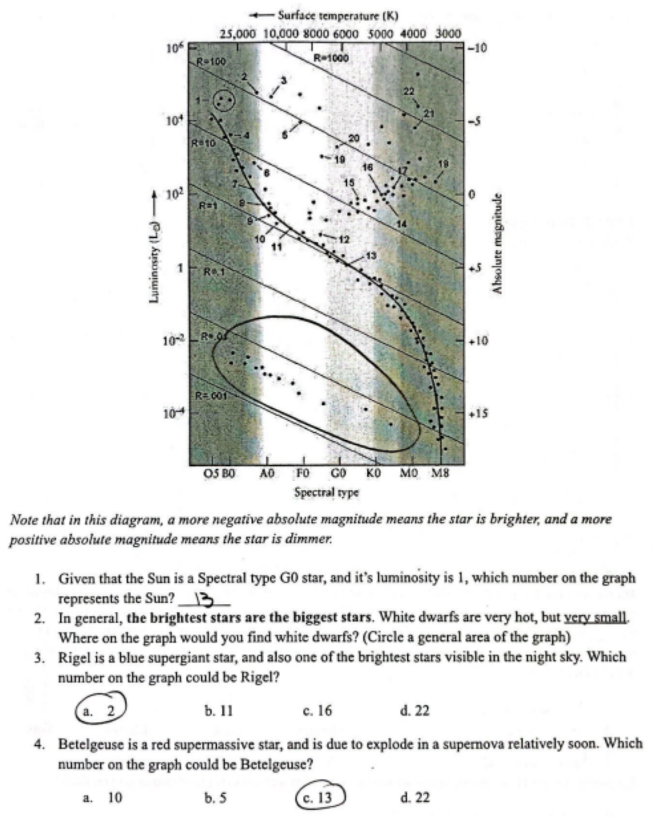
1. A person walking at a constant velocity

2. A ball rolling down an inclined plane

3. An arrow shot straight into the air

Figure 19: The kinematics graphing section of Student D's posttest, showing a reasonable understanding of kinematics scenarios. There are five correct sketches (all of scenario one; scenario three, position and acceleration).

Finally, an example of a student who doesn't seem to have gained much graphicacy knowledge from the project is Student E from Period 7. The student responded to the survey with higher confidence ratings on the posttest. Nevertheless, this student did not do well on the kinematics graph part on either the pre or the post test. They did improve the complex graphing section slightly, getting three out of four of the questions correct for the H-R diagram section on the posttest. Interestingly, for the last question, Student E answered 13, which was the correct response— and the response they gave— for question one. Why they answered 13 (which represents the Sun) twice is unknown, as it is clear that the answer couldn't have been the same for both questions. By process of elimination, that is the only response they should've avoided.



Note that in this diagram, a more negative absolute magnitude means the star is brighter, and a more positive absolute magnitude means the star is dimmer.

1. Given that the Sun is a Spectral type G0 star, and it's luminosity is 1, which number on the graph represents the Sun? 13
2. In general, **the brightest stars are the biggest stars**. White dwarfs are very hot, but <u>very small</u>. Where on the graph would you find white dwarfs? (Circle a general area of the graph)
3. Rigel is a blue supergiant star, and also one of the brightest stars visible in the night sky. Which number on the graph could be Rigel?

   [✓ a. 2] b. 11 c. 16 d. 22

4. Betelgeuse is a red supermassive star, and is due to explode in a supernova relatively soon. Which number on the graph could be Betelgeuse?

   a. 10 b. 5 [✓ c. 13] d. 22

Figure 20: The H-R diagram section of Student E's posttest. By getting questions one, two, and three correct, they indicate that they have a good understanding of how to read the graph axes. However, for an unknown reason they answered 13 to both question one and question four.

Conclusion

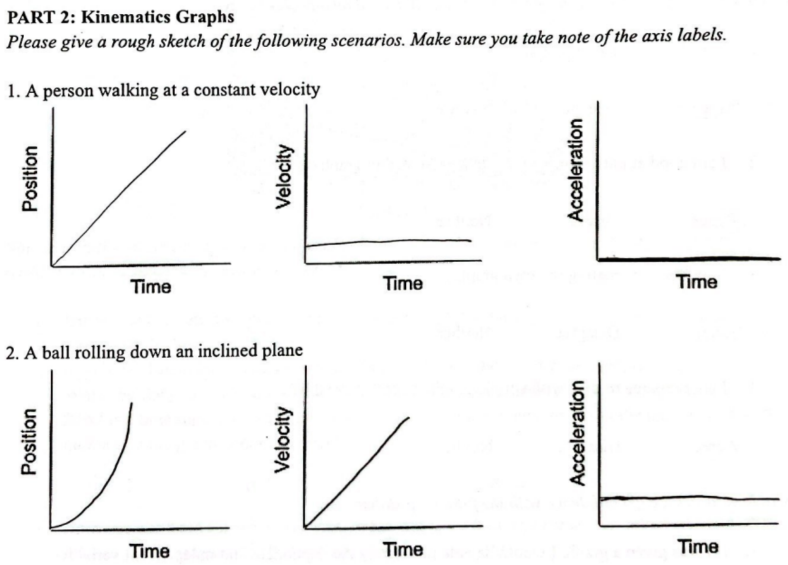
➢ Takeaways

After the 15 week teaching practicum and grading all the posttests, there were a few important takeaways from the research.

1. An increase in confidence does correlate to some degree to an increase in test scores.
2. Kinematics graphs continue to be an area of difficulty for students.
3. Students can learn how to draw information from complex graphs. Interestingly, this strength is different from honors to general.
4. There continues to be a reliance on written information rather than the graph.

First, the purpose of the survey part was to get an idea of student comfortability with graphicacy. Across all classes, students responded with more positive answers on the posttest. This means that for section one, more students responded *agree*, signaling that they felt more comfortable reading graphs, understanding data presented in graphs, creating their own graphs, and dealing with graphs later in their lives. For section two, there was an increase in responses for *5 (very confident)*, communicating that students felt more confident identifying dependent and independent variables on a graph, plotting data by hand, using a graph included in a word problem, and finding a point on a graph. Some of these questions were then assessed in the kinematics and complex graphs parts of the test. The data shows that this increase in confidence did indeed translate to an increase in correct responses for the assessment portion. For example, survey section one, question three asked students if they were good at creating their own graphs. For most students, this uptick in positive responses came with more correct responses on the kinematics graphing part of the test. There were some students for which this was not true, but the general trend was that student belief in their ability to create their own graph translated to more correct answers. Survey section two, question three probed student confidence in ability to use graphs included in word problems to answer questions, and this is exactly what the phase diagram section of the test was assessing. Survey section two, question four asked about finding points on a graph, and this is what the H-R diagram section assessed. Where there was an increase in confidence, once again every class— to different degrees— showed an ability to use the graph to answer questions with this section.

A second takeaway from this research is the fact that kinematics graphing is a difficult subject to teach! Despite taking a considerable amount of time to teach kinematics graphs, the posttest scores in the general classes showed that students continued to struggle, even if they felt more confident. As a reminder, I decided to include kinematics graphing during the year as part of the physics curriculum for all the classes, even general. Kinematics graphing flows naturally from learning about constant velocity and acceleration, but about a week was also devoted to just practicing these graphs. Nonetheless, it seems that a week was not enough time to capture student comprehension of the concepts, as can be evidenced by the low posttest scores for all the general classes. On the posttest, 10% of responses were correct on seven of the nine graphs, but only three of the nine graphs had 30% of responses correct. It may be noteworthy to mention that the classes hadn't seen kinematics graphs in any great depth since finishing 1D Kinematics about seven weeks before taking the posttest, but that is where conceptual aspects should come into play. If the students understood the graphing on a conceptual level instead of memorizing certain situations and what the graphs should look like, then in theory the scores should have been better. This can be seen with the honors class, which was more capable of conceptualizing kinematics graphing. The honors class was able to get at least 30% of responses correct on seven out of the nine graphs on the posttest. However, honors also had a slightly longer time learning this unit, about two weeks. What this tells me is that no matter what, kinematics graphing is a challenging topic to teach since it is very conceptual, especially when talking about velocity or acceleration graphs. More time and more practice is necessary to continue to reinforce the concepts. Figure # demonstrates an honors student who nearly got all the responses correct for the kinematics graphing section, but made a small error in the last question. This student mostly understood that acceleration is the slope of the velocity on a graph. However, they made the mistake of correlating a positive velocity with a positive acceleration. So even when the conceptual understanding is strong, there is still the possibility of getting tripped up. Ultimately, kinematics graphing is a valuable topic to train though, because by cementing the idea that graphs are not literal representations of the real world students will have a better conceptual knowledge of other types of graphs they might encounter.



PART 2: Kinematics Graphs

Please give a rough sketch of the following scenarios. Make sure you take note of the axis labels.

1. A person walking at a constant velocity

2. A ball rolling down an inclined plane

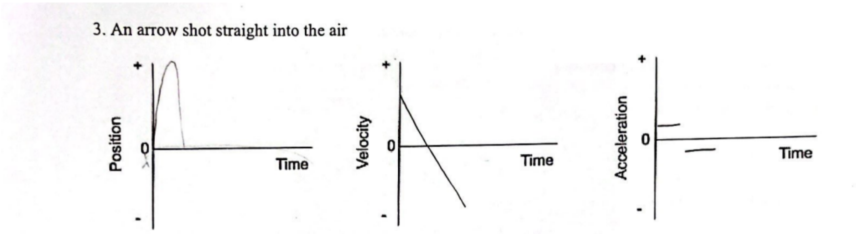


Figure 21: An exemplary response for the kinematics graphing part of the test from honors. Even the best responses still had errors— in this case, in the acceleration vs time graph for scenario three.

The methodology was successful in training students to read and use information found in complex graphs. The reason that a phase diagram and an H-R diagram were chosen for this portion of the test was because neither of these graphs would be used or referenced at any point during the year in physics. It was also unlikely that students would be introduced to either of these graphs in their other concurrent classes, since by the time that students take physics they have already taken chemistry, and if they are in physics that means they probably have not taken cosmology, which is another elective offered at the school. But even though students were not shown, let alone taught how to read either of these graphs, scores on the complex graph part of the test went up across the board. This demonstrates that the methodology was successful in teaching students skills in graphicacy, specifically how to interpret graphs. It is the degree for which this increase was seen for each class that is more interesting to note. On the posttest, honors physics improved most with the phase diagram section, while only improving a little with the H-R diagram. There are a few reasons as to why this might be the case. The main reason is that the phase diagram assessed how well a student could gain conceptual knowledge of a graph, while the H-R diagram evaluated the more superficial skill of reading a graph's axes. Going off of this, the honors class is already full of students who are passionate about science, and it's possible that many of the students in the room had already seen an H-R diagram before coming into my class. Perhaps this population of students did equally well on the H-R diagram section on both pretest and posttest, leaving little room for improvement. At the same time, the honors class likely picked up on graphing skills better than the general physics classes did, and learned to use the visual clues in the graph to answer the questions for the phase diagram. This is why the honors class saw significant progress on the phase diagram section of the test, and the general classes did not. What the general classes did improve on, however, was the H-R diagram. This also stems from the difference in skills that the two graphs evaluated. The general physics classes had a greater bridge to gap in terms of graphicacy skills during the course of the semester. If many of the general physics students came in not knowing how to read graph axes and find points on the graph, then naturally trying to interpret a complicated diagram such as the H-R diagram would be a challenge. The honors students may have come into the class already having a decent grasp of these skills. The general students had to be refreshed, retaught, or taught for the first time how to find points on a graph. But once this information was taught with the focused instruction of graphicacy, then scores for this section shot up.

The complex graph part of the test was simultaneously the most interesting part of the research and the part with the most issues. As mentioned, there were two issues that arose in this section. One of these issues was with the phrasing of the written background information for the phase diagram. However, this mistake also led to an interesting finding. The background information was not incorrect, but it was a little misleading. It made a point to say that high temperatures cause elements to be in the gas phase, while high pressures cause elements to be in the solid phase. If this is all the information you were given, then it makes sense to infer that when both the temperature and pressure are very high, then an element might be in a superstate of solid and gas, as question four asked. This is how most students responded to this question. However, there should be two clues which should've steered students away from that answer. One is experience. Thinking logically, it does not make sense for an element to be both a solid and a gas— in between these is another phase of matter. But perhaps this is just a physical phenomenon that students haven't seen before. A second clue should help get students to the correct answer, which is the graph provided. On the graph, there are three clear sections which each correspond to a state of matter. Question four asked about a supposed state which was between two of the other states. It should follow that the state of matter between these other two states of matter should be a superstate of them. Of course, this does not guarantee that the response will be correct, since a student has to get the three questions beforehand correct in order to get the question correct. However, what is interesting is that even if students matched all three states of matter correctly, some would still answer the fourth question incorrectly— most often with *solid and gas*. This actually happened on 39% of the responses on the pretest. Then, instead of decreasing, it actually increased to 45% of all responses on the posttest, as seen in Figure 22. A real example of this can also be seen in Figure 16. The reason for this is clear: reliance on written information. While this is not exactly one of the issues that was found in Plananic's research, it is related. Plananic found that "Even though students demonstrated that they were capable of using different strategies for reasoning about graphs, the preferred strategy in physics domain tended to be the use of formulas" (Plananic, 10). Of course, in this case, students could not use a formula. But rather than rely on the graph, students chose to use the background information; for some, probably against their own instinct. It goes to show that even though a majority of students stated otherwise in the survey section of the test, students have a lack of trust in themselves to interpret a graph and use it as a source of information. They would rather rely on something explicitly stated or a formula given to them by the teacher.

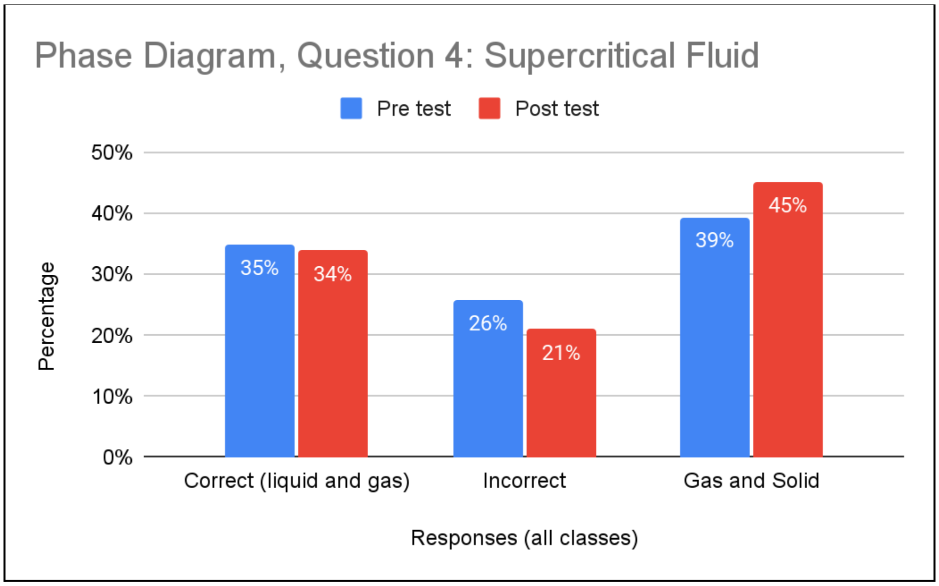


Figure 22: The data from the fourth question of the phase diagram section, which asked which two stages of matter a substance could be in at both a high temperature and pressure. The chart shows how a majority of responses were "gas and solid", a response that originates from the background information given with the graph.

➢ Effectiveness of research

The results of this research were measured entirely through the pre and post test. This is the most direct method of comparison, as well as making it easy to assess student knowledge of graphicacy. With this method of research, a statistical analysis could be run to verify a significant difference in the means. Additionally, the raw test scores could be used to calculate the learning gain after the practicum. This was done with the learning gain equation introduced by Hake in

1998, “as a rough measure of the effectiveness of a course in promoting conceptual understanding". (McKagen, 1). The equation takes the difference between the average posttest score and average pretest score and divides it by the difference of a perfect score and the average pretest score, as seen in the equation below.

$$\text{Learning gain} = \mathbf{<g>} = \frac{Avg.\,post\ score - Avg.\,pre\ score}{100 - Avg.\,pre\ score}$$

The average scores for honors and general physics were inputted separately as an exercise to see how much of a difference there was between the two student populations. This was done because the average pre and post test scores were much different for honors as compared to general. For honors, the learning gain was calculated as

$$<g>_{\textbf{Honors}} = \frac{(8.870/17)-(6.826/17)}{1-(6.826/17)} = \mathbf{0.201}$$

A learning gain of 0.201 falls in the average range (Hake, 1). Using the average scores for the general physics classes, the learning gain was found to be

$$<g>_{\textbf{General}} = \frac{(6.180/17)-(4.128/17)}{1-(4.128/17)} = \mathbf{0.159}$$

which is a bit below average. The general classes having a lesser learning gain is actually a bit surprising, given that it was the general classes that had more to gain. It serves as a reminder of why the honors students take the honors level course; these students are really striving to learn.

Overall, using the pre and post test was an effective way to conduct the research. Although some of the questions had to be reevaluated for correctness after issues of printing in black and white (see Section 5b), the pre and post test was a simple way to collect data and gauge how confident students were in their graphicacy. The drawback of this method is that a traditional test format, such as the one used, is not always the most accurate reflection of student learning[8], and really requires a larger sample size (of respondents and questions) to provide comprehensive results. At the same time, I was instructed by the IRB not to take too much time out of the class with the research, and using a pre/post test is one of the most time-effective methods to collect data quickly. Since the test was also full of graphs, it offered many

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[8] Alternatives to Traditional Exams and Papers, *Indiana University Bloomington*

opportunities to ask diverse questions which require students to think deeper. One example is question two of the H-R diagram section, which asks students to circle an area of the graph instead of finding a specific point. This challenges students to really think about what the graph axes mean and, in the case of the H-R diagram, where the cluster of white dwarf stars is.

➢ Effectiveness of methodology

As mentioned, the approach to remedy the lack of graphing skills present in high school and college students was quite simple. All it involved was a focused instruction of graphicacy in the normal physics curriculum. What's more, the test used for measurement of the learning was not meant to directly assess a student's knowledge of the normal physics curriculum, but students' ability to read and create graphs. From the relatively small sample size from which the data was taken, it seems like the methodology was successful; there was improvement in student's graphicacy confidence, ability to sketch kinematics graphs, and capability to draw information from complex graphs. Students were never formally taught any of the material on the test or showed either of the graphs, but were still able to use knowledge gained from the implemented methodology to do significantly better on the posttest. Of course, these results were obtained from a mere 15 week practicum from which there were only slightly more than 60 responses for pre and post test, so claiming this with complete certainty is not fully justifiable without further research.

➢ How to improve/future research

There are many ways to improve upon the research done in this project. First and foremost for gaining better results is a longer time spent in the classroom using this approach to teaching physics, and a larger sample size of respondents. Given the initial context of the project, however, these factors were out of my control. My primary goal during the project was to teach high school physics. The project to teach students graphicacy was always meant to be a byproduct of the way that the lesson plans were designed and delivered. A longer time within the classroom for the study would be better, as it would allow for greater exposure to graphing techniques and would better show student growth over time.

What I did have control over was the graphing test. These results which have been discussed were all derived from the responses on the pre and post test. Clearly, then, every part of the test was extremely important with regards to gathering information. In retrospect, there were certainly ways to improve the effectiveness of the test. Aspects of the test that could have been more efficient include the phrasing of the questions, questions that the test asked, and the length of the test. The test was not meant to assess student comprehension of physics or other science concepts; it was only supposed to be an evaluation of graphicacy. Yet, with my limited experience in designing surveys and tests, it's possible that instead of evaluating a student's ability to read or create graphs, the test evaluated things like language skills or physics knowledge. Therefore, some rephrasing of the questions would most likely provide clearer results. One example of this is for question four of the phase diagram section, the issues which have already been considered (see Results: Pretest/issues with the test). Yet another example of where this could be done is in scenario two of the kinematics graphing part. Scenario two of the kinematics graphing part says *A ball rolling down an inclined plane* (see Figure 1). For me, a student who has been studying physics for three years, I did not think twice about using the phrase *inclined plane*, as I understand this to be a flat surface raised at an angle above the horizontal. However, for a high school student, it's possible that this phrase was unknown to them, or unclear (as a reminder, the test was translated to Spanish and Portuguese for non-native speakers). Perhaps it would have been better to simply say *A ball accelerating uniformly.* After all, this is the real message I was trying to get across with this scenario: that the graphs to be drawn should be of uniform acceleration. For the purposes of this research, getting right to the point might have been the best option, since that is what I was trying to assess. The reason I did not decide on this is because drawing graphs using the prompt *uniform acceleration* is something that I explicitly taught during the teaching practicum, and I was trying to avoid including information explicitly taught during the regular school year in the graphing test. Nonetheless, by using physics language I may have been assessing a student's knowledge of language in addition to their ability to graph. This is where better decisions might be made in the future.

A slightly longer test and slightly different questions would be another way to get more conclusive results. The test that was used during this research was focused on being concise and was also my first attempt at writing a test used for research. The questions that were used were very intentional for demonstrating a student's conceptual knowledge of the graph. However, what was lacking in the test were some questions about some more basic graphing skills. After completion of the teaching practicum and the research, some ways of adding to the test while also keeping it brief became clear. Having questions on the test asking specifically about identification of graph axes, units, scales, slope, and area under the curve are some options. These questions would go a long way towards making conclusions about student improvement in graphicacy.

The final option for improving future research is to do away with the pre and post test format entirely and instead opt for a more progressive form of assessment. A formal test or survey is easy to grade, but possibly puts certain students at a disadvantage. Future research could look into alternative methods of testing student knowledge that doesn't take much time out of class and can be easily graded, and includes all the prior adjustments mentioned.

With this entire experience under my belt I now know how to better pace my lessons and format the method of assessment to measure the results of the study. If I end up as a teacher in the classroom, I would not be opposed to attempting another research opportunity like this again in the future.

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Appendix

Lesson Plan Title: Constant Velocity Lab

Teacher's Name: Simon Rees **Subject/Course:** General physics
Unit: Velocity **Grade Level:** 11/12

Overview of and Motivation for Lesson:
Students will complete a lab with battery-powered cars in order to investigate constant velocity.

Stage 1-Desired Results

Standard(s):

- HS-PS2-1. Analyze data to support the claim that Newton's second law of motion is a mathematical model describing change in motion (the acceleration) of objects when acted on by a net force.

Aim/Essential Question:

- How do you know if an object has constant velocity?

Understanding(s):
Students will understand that . . .

- velocity is a change in distance over a change in time
- constant velocity means that the change in distance over a certain time is unchanged

Content Objectives:
Students will be able to . . .

- Plot a simple graph of position over time
- Find the slope of a straight line
- Justify when objects have constant velocity
- Predict what happens when objects are accelerating

Language Objectives:
ELD Level 4-5 *Students will be able to . . . in English*

- Explain in writing what constant velocity is, use content-specific vocabulary

ELD Level 1-3 *Students will be able to . . . in English*

- Verbally explain what constant velocity is, justify constant velocity using if… then statement

Key Vocabulary

- Constant velocity
- Acceleration
- **Plot**
- Graph
- Distance over time
- **Slope**
- Change in

Stage 2-Assessment Evidence

Performance Task or Key Evidence

- Plotting points on a distance vs time graph and finding the slope
- Completion of the lab worksheet

Key Criteria to measure Performance Task or Key Evidence

- The line on the graph should be a straight line
- Constant velocity is when the change in distance over a certain change in time does not change.

Stage 3- Learning Plan

Learning Activities:

Do Now/Bell Ringer/Opener: 5 min

QOTD: What is the fastest speed humans have reached in a vehicle that drives on the ground?

Answer:

Car on tracks: 763 mph (speed of sound is 767)

Learning Activity 1: 5-7 min

What we will be doing today is a constant velocity lab. I won't tell you/remind you what constant velocity is, because that's the point of the lab! However, we will also be graphing points to show graphically what constant velocity should look like.

Demonstrate to students how to graph on the board.

Learning Activity 2: 20 min

Split students into 4 groups. Groups will be random (count off, hold up your number when I call on you). Each student in the group's role is to measure the time it takes to cover 50 centimeters. Groups will work in the hallway to set up for the lab, measuring 50 cm segments with pencils. Do a very quick demo setup with 3 volunteers.

Students will run two trials with the same car, then swap cars with another group and run two more trials. Results can be recorded on the lab worksheet.

Learning Activity 3: 20 min

Each student works together in their group to individually plot their graphs on graph paper. Then students individually answer the questions on the lab worksheet.

For ELLs, I will come around and talk with them and ask for a verbal explanation.

Summary/Closing 3-5 min

Velocity graph activity as a whole class: if the cars have a constant velocity, what would the graph of the velocity over time look like? If time, ask the class what some sources of error from the lab could be.

Multiple Intelligences Addressed:

☐ Linguistic
☐ Spatial
☐ Logical-Math
☐ Interpersonal
☐ Musical
☐Intrapersonal
☐Bodily-kinesthetic
☐Naturalistic

Student Grouping

☐ Whole Class **☐ Small Group** ☐ Pairs **☐ Individual**

Instructional Delivery Methods

☐ Teacher Modeling/Demonstration ☐ Lecture **☐ Discussion**
☐ Cooperative Learning ☐ Centers ☐ Problem Solving
☐ Independent Projects

Accommodations	**Modifications**

Homework/Extension Activities:

Finish the lab worksheet if not done. Will be collected on Friday.

Materials and Equipment Needed:

- Battery-powered constant-velocity cars
- Graph paper
- Phone timer

Adapted from Grant Wiggins and Jay McTighe-*Understanding by Design*

Constant Velocity Lab

Vocabulary you may not know:

- *Increment: a smaller part of a bigger thing, where all the smaller parts are the same*

In this lab you will be measuring how long it takes for your car to travel 200 cm in 50 cm increments. You will assign one person in the group to each 50 cm increment (so there will be a separate person for the four increments). That person is responsible for timing how long it takes for the car to travel their designated 50 cm.
Once the car has traveled 200 cm, everyone compares times.

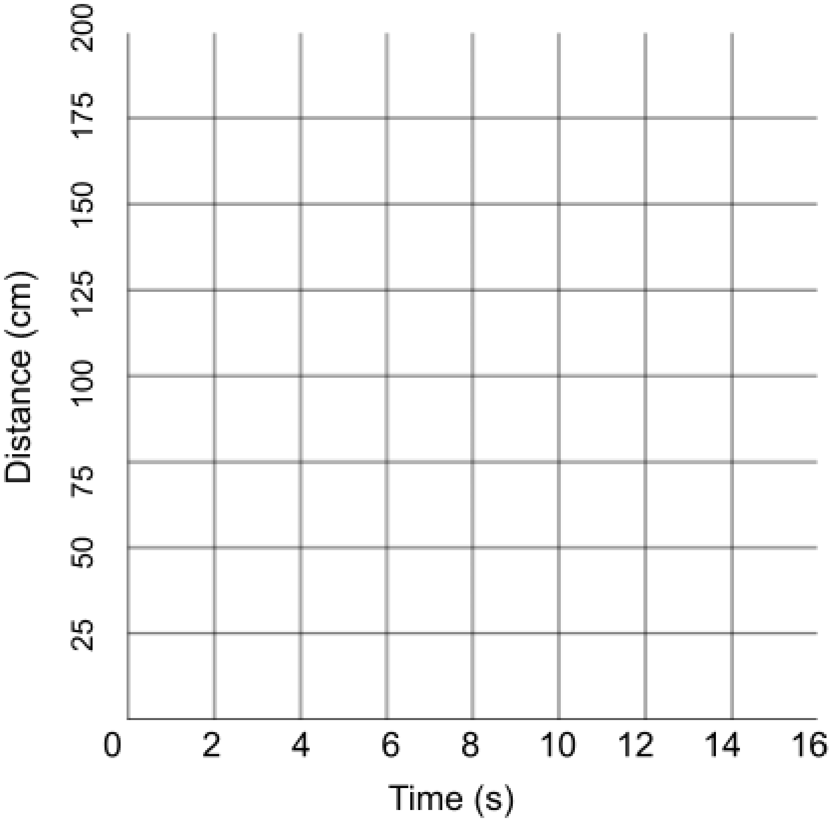
1. What do you notice about the time it took for the car to go each 50 cm?

____

Red Car						
Trial 1			**Trial 2**			**Avg**
Distance (cm)	**Δ**t (s)	Total time (s)	Distance (cm)	**Δ**t (s)	Total time (s)	Total time (s)
0 to 50			0 to 50			
50 to 100			50 to 100			
100 to 150			100 to 150			
150➡200			150➡200			

Blue Car						
Trial 1			**Trial 2**			**Avg**
Distance (cm)	**Δ**t (s)	Total time (s)	Distance (cm)	**Δ**t (s)	Total time (s)	Total time (s)
0 to 50			0 to 50			
50 to 100			50 to 100			
100 to 150			100 to 150			
150➡200			150➡200			

Now plot your data *(see Mr. Rees or Mrs. Friberg for help)*



To find the slope of your line, you do the total distance divided by the total time.

Slope = $\frac{distance}{time}$= $\frac{200\ cm}{total\ time}$= ___________ cm/s

2. What does the slope represent? *Hint: what is the unit for the slope?*

3. What do you think constant velocity means? Try to give a definition.

4. Compare the line of the red car to the line of the blue car. Which line had the greater slope? Does that make sense?

Lesson Plan Title: Extension Acceleration Lab

Teacher's Name: Simon Rees **Subject/Course:** General physics
Unit: Acceleration **Grade Level:** 11/12

Overview of and Motivation for Lesson:
Students will complete a lab with pull-back toy trucks in order to investigate non-constant velocity and acceleration.

Stage 1-Desired Results

Standard(s):
- HS-PS2-1. Analyze data to support the claim that Newton's second law of motion is a mathematical model describing change in motion (the acceleration) of objects when acted on by a net force.

Aim/Essential Question:
- What happens when an object's velocity is not constant?

Understanding(s):
Students will understand that . . .
- acceleration is a change in velocity over time
- acceleration is also when, over a specific period of time, the distance traveled increases with every passing period of time.

Content Objectives:
Students will be able to . . .
- Plot a simple graph of position over time when the object is accelerating
- Justify that the object does not have constant velocity by using deductive reasoning

Language Objectives:
ELD Level 4-5 *Students will be able to . . . in English*
- Explain in writing what linear acceleration is, use content-specific vocabulary

ELD Level 1-3 *Students will be able to . . . in English*
- Verbally explain what linear acceleration is, justify their answer using if… then statement

Key Vocabulary
- Constant velocity
- Acceleration
- **Plot**
- Graph
- Distance over time
- Velocity over time
- Change in
- Increasing/decreasing

Stage 2-Assessment Evidence

Performance Task or Key Evidence
- Plotting points on a distance vs time graph
- Completion of the lab worksheet

Key Criteria to measure Performance Task or Key Evidence
- The line on the graph should not be a straight line
- Since the amount of time that the truck took to go 50 cm was shorter after every interval, then the truck cannot have constant velocity, and must therefore be accelerating.

Stage 3- Learning Plan

Learning Activities:

Do Now/Bell Ringer/Opener: 5 min

QOTD: What is the fastest speed humans have ever reached?

Answer:

Trick question, sort of. Aren't we all going 1000 mi/hr on the Earth as it rotates?

s03e22》Malcolm in the Middle; Intro to Show - YouTube

Learning Activity 1: 5-7 min

What we will be doing today is a lab with a pull back truck. We will also be graphing points to compare with yesterday's graphs.

Demonstrate to students how to graph on the board.

This lab is extremely similar to the lab yesterday! Don't get confused. You will do the exact same procedure, only this time with a different vehicle: the truck. That is how you run an experiment, remember? You should only change one variable at a time; in this case, it's the truck. My hypothesis (not written in if...then form) is this:

Upon releasing the truck, it will not move at a constant velocity.

Can you collect data that will support/reject this hypothesis?

Learning Activity 2: 20 min

Students go into the same 4 groups. Each student in the group's role is to measure the time it takes to cover 50 centimeters. Groups will work in the hallway to set up for the lab, measuring 50 cm segments with pencils.

Students will run three trials with the same car. Results can be recorded on the lab worksheet.

Learning Activity 3: 20 min

Each student works together in their group to individually plot their graphs on the lab paper. Then students individually answer the questions on the lab worksheet.

For ELLs, I will come around and talk with them and ask for a verbal explanation.

Summary/Closing 3-5 min

We learned that a change in position over time is called velocity. Now we learned that a change in velocity over time is called acceleration. But can you have a change in acceleration over time? What is it called? [answer: yes, jerk]

Multiple Intelligences Addressed:

☐ Linguistic ☐ **Logical-Math** ☐ Musical ☐Bodily-kinesthetic

☐ **Spatial** ☐ **Interpersonal** ☐**Intrapersonal** ☐Naturalistic

Student Grouping

☐ Whole Class ☐ **Small Group** ☐ Pairs ☐ **Individual**

Instructional Delivery Methods

☐ Teacher Modeling/Demonstration ☐ Lecture ☐ **Discussion**

☐ **Cooperative Learning** ☐ Centers ☐ **Problem Solving**

☐ Independent Projects

Accommodations	**Modifications**

Homework/Extension Activities:

Finish the lab worksheet if not done. Will be collected next class.

Materials and Equipment Needed:

- Pull-back accelerating trucks
- Graph paper
- Phone timer

Adapted from Grant Wiggins and Jay McTighe-*Understanding by Design*

Acceleration Lab

Vocabulary you may not know:

- *Support / reject the hypothesis: based on the data, you think the hypothesis is correct / incorrect.*

Just like yesterday, in this lab you will be measuring how long it takes for your truck to travel 200 cm in 50 cm increments. However, in this lab you will use a timer and a slow-motion video. Place the timer on the ground and start it when the truck is released. When you pull back the truck, make sure you place it two tiles ahead of the start line, and then pull it back to the start line to let it go. You will compare your results to the constant velocity lab to either support or reject the hypothesis.

Hypothesis: Upon releasing the truck, it will not move at a constant velocity.

Trial 1			**Trial 2**		
Distance (cm)	Total time (s)	**Δ**t (s)	Distance (cm)	Total time (s)	**Δ**t (s)
0 to 50			0 to 50		
50 to 100			50 to 100		
100 to 150			100 to 150		
150 to 200			150 to 200		

Average	
Distance (cm)	Total time (s)
0 to 50	
50 to 100	
100 to 150	
150 to 200	

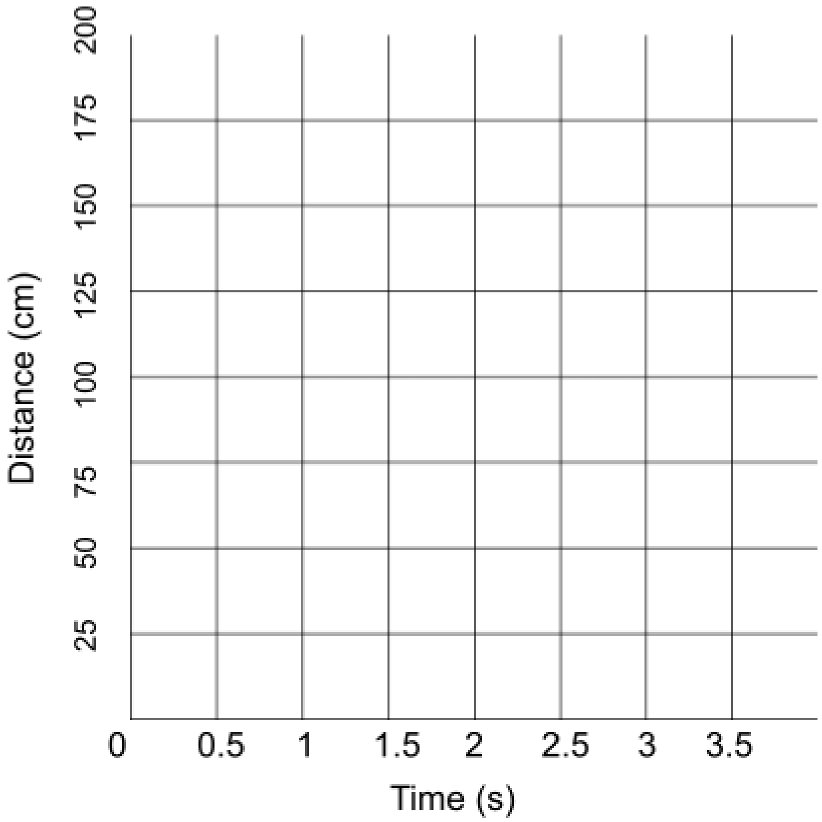
1. When you compare your **Δ**t's, what do you notice?

____

____

____

Now plot your data *(on back, see Mr. Rees or Mrs. Friberg for help)*



2. What is different about this graph as compared to yesterday's graph?

3. Slope
    a. If I asked you to calculate the slope of this graph, what units would it have? *Remember that in this case, slope is still distance divided by time.* _______________
    b. What does the slope represent? _____________________________
    c. Is the slope constant? ______________

4. What do you think acceleration means? Try to give a definition.

5. Is the hypothesis supported or rejected? <u>Make sure you justify your answer</u>.

Lesson Plan Title: Constant Velocity and Acceleration Lab Debrief

Teacher's Name: Simon Rees **Subject/Course:** General physics
Unit: Velocity and Acceleration **Grade Level:** 11/12

Overview of and Motivation for Lesson:
Review of the two previous labs to cement the understandings of what constant velocity and non-constant velocity/acceleration are, preliminary introduction of kinematics graphs, and introduction of the equation for average acceleration.

Stage 1-Desired Results

Standard(s):

- HS-PS2-1. Analyze data to support the claim that Newton's second law of motion is a mathematical model describing change in motion (the acceleration) of objects when acted on by a net force.

Aim/Essential Question:

- What is the difference between velocity and acceleration?

Understanding(s):

Students will understand that . . .

- constant velocity means that the change in distance over a certain time is unchanged
- acceleration is when the change in distance over a certain time changes
- position v time graphs for constant velocity are straight lines with slope greater than 0
- position v time graphs for acceleration are not straight lines
- average acceleration is the change in velocity over time

Content Objectives:

Students will be able to . . .

- Compare and contrast constant velocity and non-constant velocity
- Identify position graphs of constant velocity

Language Objectives:

ELD Level 4-5 *Students will be able to . . . in English*

- Explain in writing what constant velocity is, use content-specific vocabulary

ELD Level 1-3 *Students will be able to . . . in English*

- Verbally explain what constant velocity is, justify constant velocity using if… then statement

Key Vocabulary

- Constant velocity
- Acceleration
- **Plot**
- Graph
- Distance over time
- **Slope**
- Change in

Stage 2-Assessment Evidence

Performance Task or Key Evidence
- Completion of the lab worksheet

Key Criteria to measure Performance Task or Key Evidence
- Identifying when an object has constant velocity.

Stage 3- Learning Plan

Learning Activities:
Do Now/Bell Ringer/Opener: 5 min
QOTD: You get in the car and start driving. Did you accelerate?

Learning Activity 1: 10 min
Pull out the lab worksheet and go over possible answers for the graph and the slope. Ask for questions and answer them.

Learning Activity 2: 10 min
Those who finished/think they understand the velocity lab and/or acceleration lab, raise hands. I will assign each one who has finished to a new group. They are in charge of making sure the group has finished the velocity lab, including the final three questions.

Learning Activity 3: 10 min
Ask for attention to the front of the room again and begin to review the acceleration lab. Go over the graph and the shape of the graph. Is it different or the same as the graph from the velocity lab? Talk about slope. Ask for questions and answer them.

Learning Activity 4: 5 min
Have groups discuss and answer question 4.

Learning Activity 5: Remainder of class
Kahoot!

Summary/Closing 3-5 min
Talk about question 5, is the hypothesis rejected or supported? Make sure people hand in the labs! Late labs lose 5 points.

Multiple Intelligences Addressed:

☐ Linguistic	**☐ Logical-Math**	☐ Musical	☐Bodily-kinesthetic
☐ Spatial	**☐ Interpersonal**	**☐Intrapersonal**	☐Naturalistic

Student Grouping

☐ Whole Class ☐ **Small Group** ☐ Pairs ☐ **Individual**

Instructional Delivery Methods

☐ **Teacher Modeling/Demonstration** ☐ **Lecture** ☐ **Discussion**
☐ **Cooperative Learning** ☐ Centers ☐ Problem Solving
☐ Independent Projects

Accommodations	**Modifications**

Homework/Extension Activities:

No homework

Materials and Equipment Needed:

- Lab worksheets from previous classes

Adapted from Grant Wiggins and Jay McTighe-*Understanding by Design*

Name: GRADE: $\overline{}$ 50

Conceptual Physics
Quiz #1 – 1D Kinematics – **SHOW ALL WORK!**

1. What is the difference between a SCALAR and a VECTOR? Give an example of each. (4 points)

2. What is the equation for VELOCITY? What is the equation for ACCELERATION? (4 points)

3. What is the difference between DISTANCE and DISPLACEMENT? (4 points)

4. A person walks 50 meters forwards, and then 100 meters backwards in 10 seconds. Answer the following: (8 points)

a. Draw a diagram of the situation. Backwards ← → Forwards

b. What is the person's total DISTANCE travelled?

c. What is the person's DISPLACEMENT?

d. What is the person's AVERAGE VELOCITY?

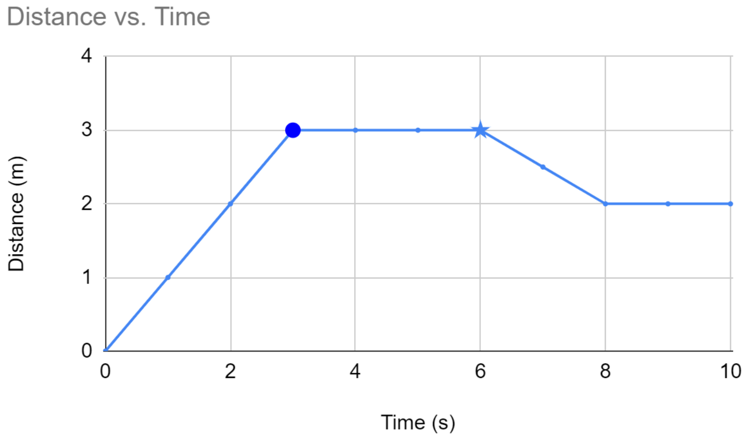
7. An Amtrak train leaving from North Leominster station can travel from a velocity of 20 m/s to 40 m/s in 20 seconds: (6 points)

a. What is the train's INITIAL VELOCITY? ___________________

b. What is the train's FINAL VELOCITY? ___________________

c. What is the train's AVERAGE ACCELERATION in the 40 second time interval? Don't forget units!

8. Look at the following graph (10 points)



a. What is the total DISTANCE travelled?

b. What is the total DISPLACEMENT?

c. What did the object do between the circle and the star?

d. What did the object do at the star?

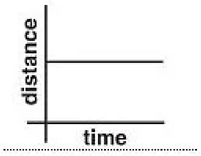
e. What is the average SPEED between 6 and 8 seconds?

9. Look at the following four graphs. (8 points)

a. Which graph shows the object moving at a constant velocity?

____

b. What does graph D show?

A


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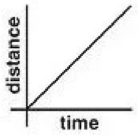
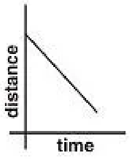
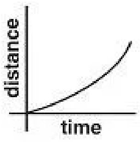


c. Is the object moving towards the origin or away from the origin (origin = 0) in graph C?

d. Which graph shows no motion?

____

C


D


10. A freight train traveling with a velocity of 18.0 m/s to the south begins braking as it approaches the train yard. The train's acceleration while braking is -0.55m/s^2. What is the train's *final velocity* after 23 seconds? (6 points)

Lesson Plan Title: Graphing Free Fall

Teacher's Name: Simon Rees **Subject/Course:** General physics
Unit: Free Fall **Grade Level:** 11/12

Overview of and Motivation for Lesson:
Students will use data provided to them to graph the position, velocity, and acceleration graphs of an object in free fall.

Stage 1-Desired Results

Standard(s):

- HS-PS2-1. Analyze data to support the claim that Newton's second law of motion is a mathematical model describing change in motion (the acceleration) of objects when acted on by a net force.

Aim/Essential Question:

- How do we express free fall with graphs?

Understanding(s):

Students will understand that . . .

- the acceleration due to gravity on Earth is -9.8 m/s/s
- the graph of x vs t in free fall is an exponential graph
- the graph of v vs t in free fall is a linear graph
- the graph of a vs t in free fall is a horizontal line

Content Objectives:

Students will be able to . . .

- plot a graph using points
- do a simple calculation to find the average acceleration
- *If time:* Identify variables in the kinematics equation for acceleration, use Desmos

Language Objectives:

ELD Level 1-3 *Students will be able to . . . in English*

- Use the content-specific words "exponential, linear, and horizontal line" to describe graphs

ELD Level 4-5 *Students will be able to . . . in English*

- Justify verbally why the graphs of x vs t, v vs t, and a vs t look the way they do

Key Vocabulary

- acceleration
- gravity
- exponential
- linear
- horizontal line
- axis
- meters per second squared

Stage 2-Assessment Evidence

Performance Task or Key Evidence

- Completion of the graphs

- Using Desmos

Key Criteria to measure Performance Task or Key Evidence

- The answers on the lab are correct

Stage 3- Learning Plan

Learning Activities:

Do Now/Bell Ringer/Opener: *5 min*

QOTD: How fast is light? Compare to circumference of Earth (40 million m)

Learning Activity 1: 15 min

Explain that today we will be working with data to graph on paper and, if there's time, also learn to graph on the computer. Review how to find a point on a graph, and how to set up axes. Also, remember to label the axes, give the graph a title, and put your name on it.

Grading:
Big enough scale - 2 points
Correct placement of points - 7 points
Smooth line connecting points - 1 point
Correct axes labels - 2 points
Title and name - 2 points

Learning Activity 2: 30 min

I will give you exactly 15 minutes to graph the first data table on a piece of graph paper. Then you have 5 minutes to graph the second data table. At the end of the time I will come around and immediately grade the graphs. If it's not done because you were off task it's automatically 1 point off out of 14.

Learning Activity 3:

Whole class: debrief, students stand up to show graphs to class. Ask about average acceleration, have one half of the class use start and end points, another half use 2-4 seconds. What is the answer? (9.8 m/s^2) Is it the same the whole time? Quick graph of this!

Now wait a minute. Doesn't this graph show no motion? If it was the position vs time graph, yes! But this is the acceleration vs time graph.

Summary/Closing 3-5 min

If time, project Desmos on board and write the equation and show that it's the same.

Multiple Intelligences Addressed:

☐ Linguistic	**☐ Logical-Math**	☐ Musical	☐Bodily-kinesthetic
☐ Spatial	**☐ Interpersonal**	**☐Intrapersonal**	☐Naturalistic

Student Grouping

☐ **<u>Whole Class</u>**	☐ **<u>Small Group</u>**	☐ Pairs	☐ Individual

Instructional Delivery Methods

☐ **Teacher Modeling/Demonstration**	☐ Lecture	☐ **Discussion**
☐ **Cooperative Learning**	☐ Centers	☐ **Problem Solving**
☐ Independent Projects		

Accommodations	**Modifications**

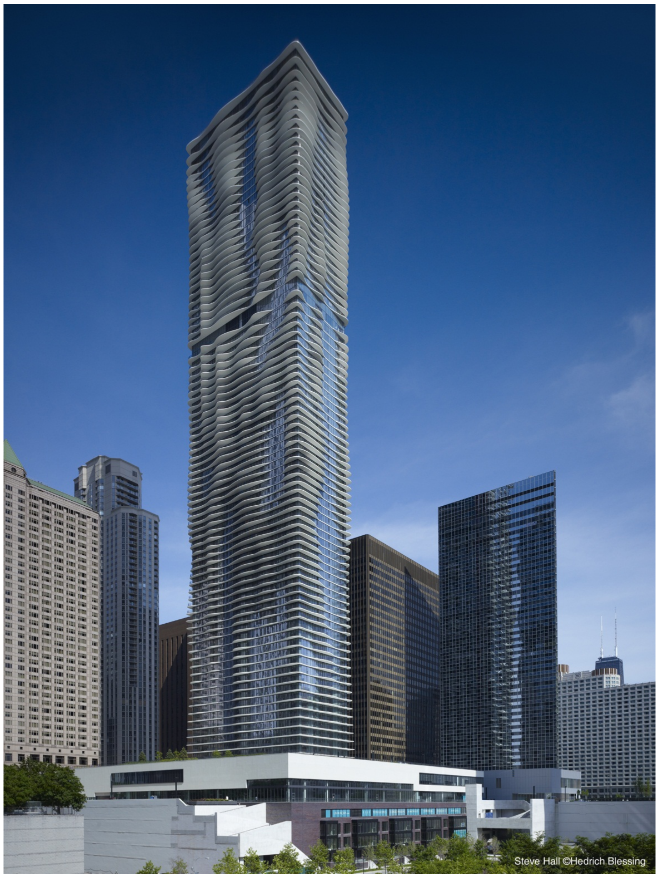
Homework/Extension Activities:
No homework

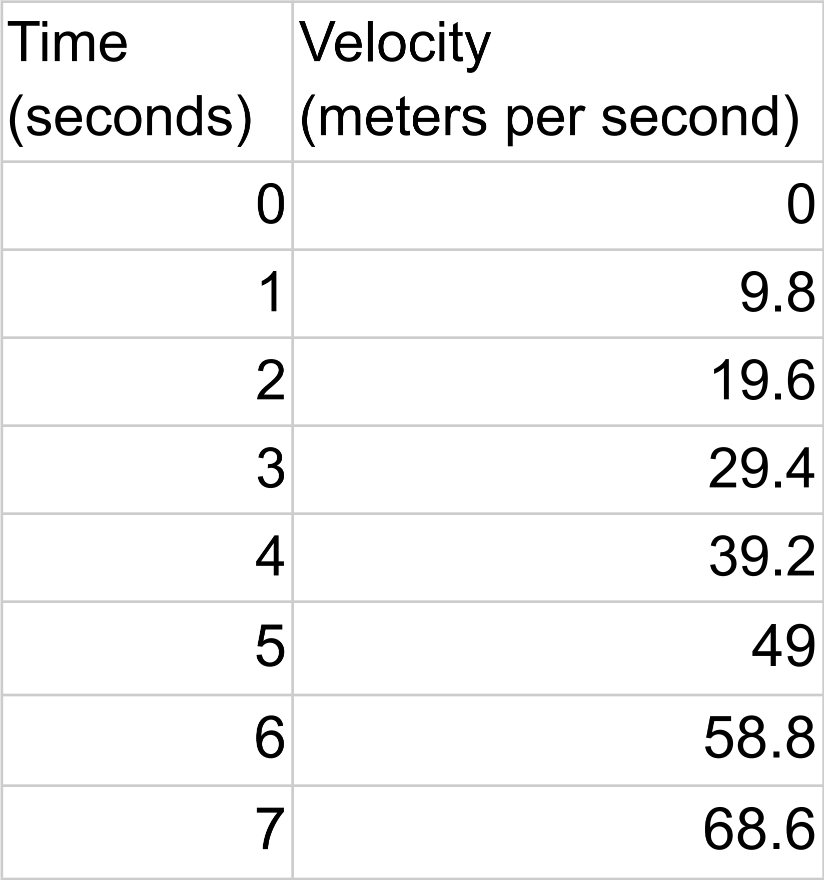
Materials and Equipment Needed:
- Graph paper
- pencils

Adapted from Grant Wiggins and Jay McTighe-*Understanding by Design*

Data for graphing:

Time (seconds)	Distance (meters)
0	250
1	245
2	230
3	206
4	172
5	127
6	74
7	10





Time (seconds)	Velocity (meters per second)
0	0
1	9.8
2	19.6
3	29.4
4	39.2
5	49
6	58.8
7	68.6

Name: Period:
Partner:

2D Vector Lab

The purpose of this activity is to show you how the sum of all the individual movements that you make can be described by one displacement vector.

Procedure:

1. Match the magnitudes (numbers) with the directions **however you want** and then write down the 6 vectors you created (Example: 2 m East)

3 m	North	______________
1 m	East	______________
7 m	West	______________
6 m	South	______________
5 m	West	______________
5 m	North	______________

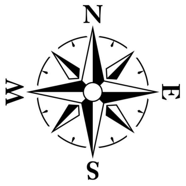
2. With your partner and a meter stick, go outside to the parking lot. You will choose a random spot to be the origin and mark it with something (anything). One partner will walk all six vectors in order, measuring the distances and walking in the correct direction using the compass app. The other partner will wait at the origin until the first partner has completed walking.
3. Once the first partner is done, the second partner will face their phone towards the first partner and write down/take a screenshot of the direction they are facing. They will then walk to where their partner is standing, making sure to measure the distance as well.
4. Once completed, answer the following questions.

1. What was the total DISTANCE that partner 1 walked?

2. What was the DISPLACEMENT of partner 2? *Don't forget to have both a magnitude and a direction!*

3. Is the magnitude of displacement a number that you could’ve figured out using simple addition and subtraction?

4. Draw an accurate diagram of the situation, including all 6 vectors, as well as the final vector connecting the start (the origin) to the end, where the first partner finished walking. Make sure to measure out the distances using the scale of 1 inch = 1 meter. Also, make sure to make exact 90° angles!



5. How close was your theoretical magnitude of displacement (the one you measured with the ruler) to your experimental magnitude of displacement (the one from the parking lot)?
Use the equation for % Error that’s written down on your equation sheet!

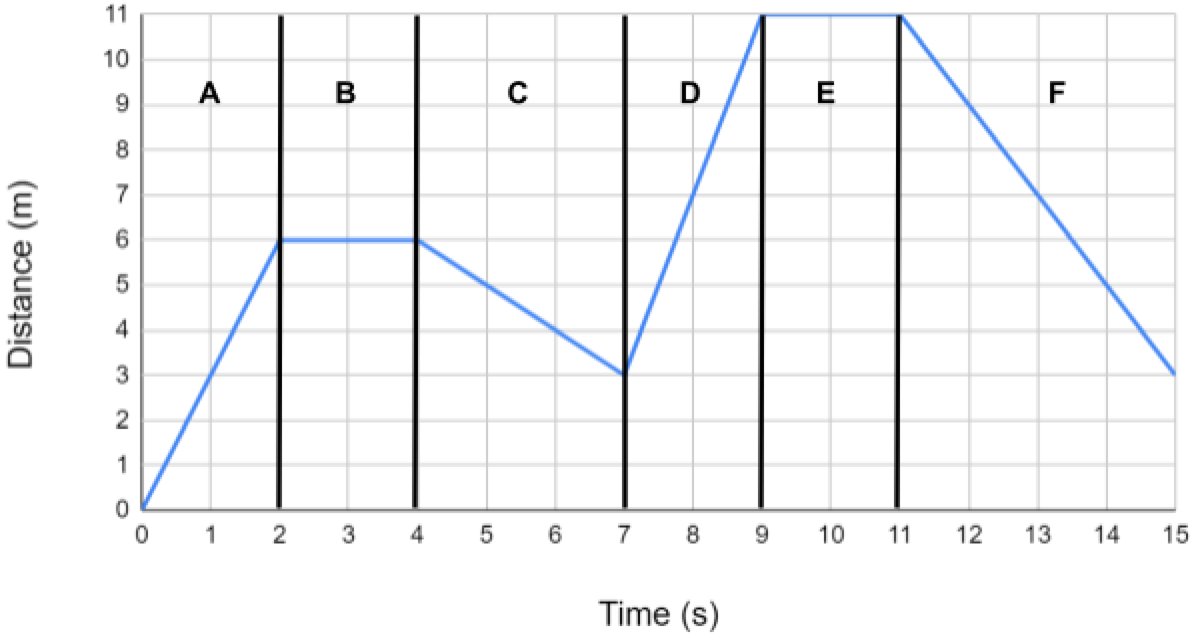
Name: Period:

Graphing Velocity vs Time

The purpose of this worksheet is to show you what a velocity vs time graph looks like when compared to its position vs time graph.

1. Look at the graph showing Principal Dubz’s position over time when he was driving. Write a few sentences below describing his motion, just like you did in yesterday’s lab.

Principal Dubz Distance over Time while driving

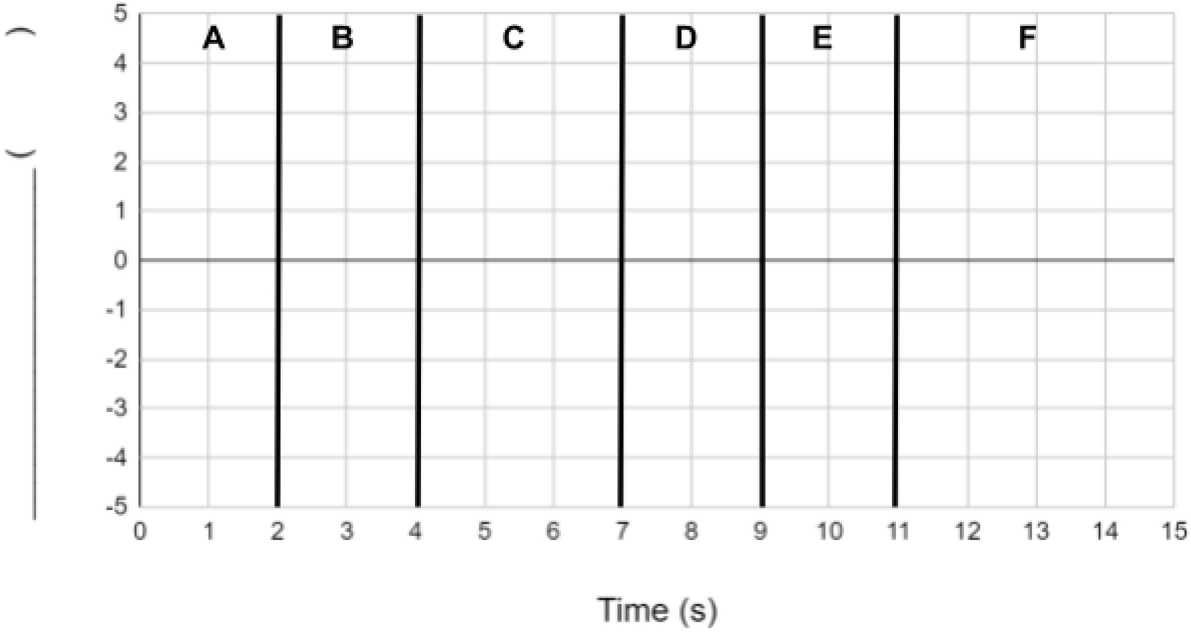


2. Calculate the slope of each section of the graph using the equation $s = \frac{d}{t}$ and write down all the speeds (same thing as velocity in this case) in the table on the back.

3. **Data table for velocities in the different sections**

Section	**A**	**B**	**C**	**D**	**E**	**F**
Velocity						

4. Now plot your velocities in the graph below.

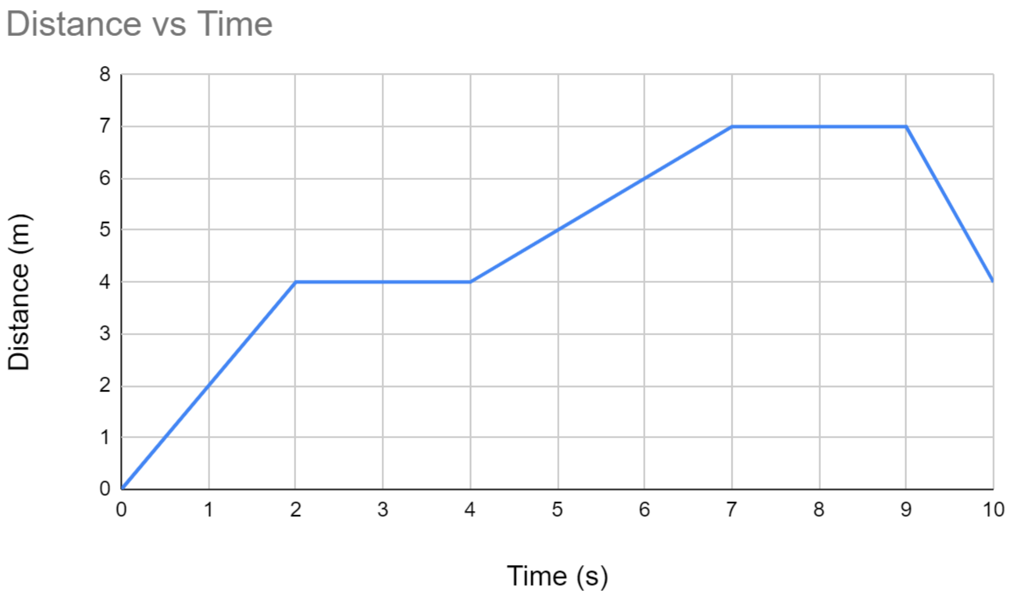


Principal Dubz's Velocity While Driving

5. During which section was Dubz driving the fastest? __________
6. During which two sections was Dubz not moving at all? __________ and __________
7. Which two sections was Dubz going forwards? __________ and __________
8. Which two sections was Dubz going backwards? __________ and __________
    a. Was his velocity positive or negative in these two sections? ________________
9. During which section was Dubz driving the slowest? __________
10. What was Dubz's total DISPLACEMENT after the 15 seconds of driving?

Name: Grade: $\frac{\quad}{20}$

General Physics
Quiz #2 - Kinematics Graphs



1. Analyze the distance vs time graph. *Answers should be a time interval, like "2 to 4 s"*
    a. When is the object going forwards? Put all the correct answers. *(2 pts)*
    b. When is the object going backwards? Put all the correct answers. *(2 pts)*
    c. When is the object stopped? Put all the correct answers. *(2 pts)*
    d. When is the object going the fastest? (*Think twice about this one! — 2 pts)*
    e. How fast is it going? (*Answer should be in m/s — 2 pts)*
    f. What is the displacement of the object? (*Answer should be in m — 1 pt)*
    g. Write a sentence or two describing what is happening. *(1 pt)*

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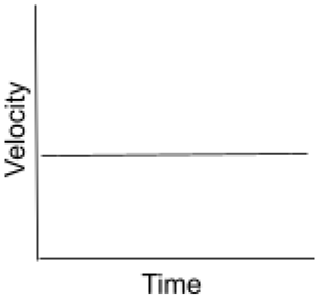
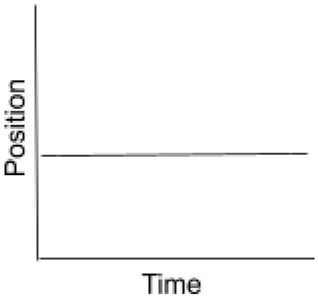
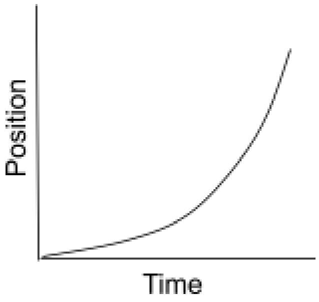
2. Match the graphs *(4 pts)*
    a. Constantly increasing velocity
    b. Constant velocity

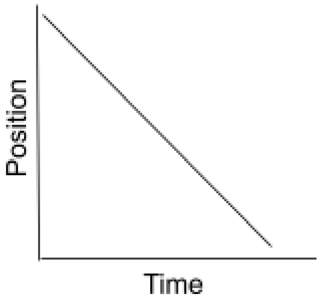
c. Negative velocity

d. Zero velocity









___________ ___________ ___________ ___________

3. Sketch the following graphs *(4 pts)*

a. An **acceleration vs time** graph for constantly increasing velocity

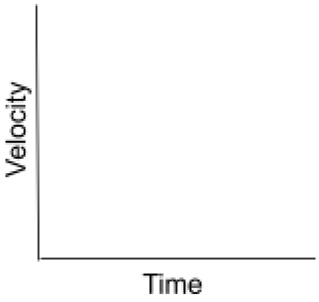
b. A **velocity vs time** graph for constant positive acceleration, like free fall

c. A **position vs time** graph for constant negative velocity starting at zero

d. A **velocity vs time** graph for constantly decreasing velocity

A

B



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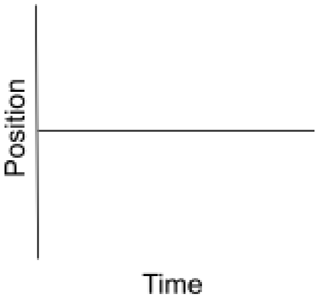

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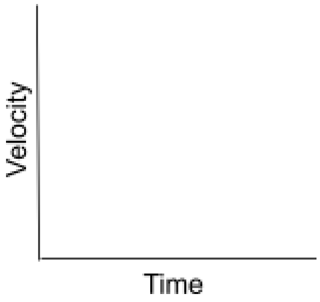


Extra credit (1 pt): What is the acceleration due to gravity on Earth in m/s^2? _________

Honors Physics:
Phet Projectile Motion Lab/questions

https://phet.colorado.edu/sims/html/projectile-motion/latest/projectile-motion_en.html

Directions:

1. Choose the “Vectors” option
2. Check the option “components”, uncheck the box “Air resistance”, and check the boxes “velocity vectors” and “acceleration vectors”.
3. Fire! Play around with it for a minute or so.
4. Complete the following questions.
    a. As the projectile flies through the air, what happens to the vertical velocity?
    b. What happens to the horizontal velocity?
    c. What happens to the acceleration?
5. For the second part, go to the “Lab” section.
6. Make sure that the “air resistance” box is NOT checked. We want to investigate how projectile motion would look in a perfect vacuum.
7. Your job is to research how all the factors in the table affect the different parts of projectile motion.
8. Remember: in order to definitively figure out what effect a certain factor has on the projectile motion, you should **only change one factor at a time.**

Table 1: No air resistance

	Time in air	Max height	Range
Initial launch velocity	Increased launch velocity means an increased time in the air		
Angle of launch			
Initial height of launch			
Gravity			
Mass of projectile			
Size of projectile			

Give me 3 different configurations of the cannon that will allow me to hit the target with three stars.

- ➢
- ➢
- ➢

9. Once you have completed the table with no air resistance, go ahead and check off the air resistance box and fill out the table again. This time, I want you to compare the results for each factor with the results you got in the previous table.

Table 2: Firing with air resistance

	Time in air	Max height	Range
Initial launch velocity	Air resistance decreases the time in the air.		
Angle of launch			
Gravity			
Mass of projectile			
Size of projectile			
Altitude			

Questions:

1. Which angle makes projectiles go the farthest?
2. Why, when considering air resistance, does the size of the projectile affect projectile motion, but not the mass?
3. Why can you shoot much farther when your initial height is above zero? In other words, why is it always preferred to have the “high ground?”

Lesson Plan Title: Graphing projectile motion

Teacher’s Name: Simon Rees **Subject/Course:** General physics
Unit: Projectile Motion **Grade Level:** 11/12

Overview of and Motivation for Lesson:

Students have learned about free fall and projectile motion, and they have practice in solving word problems for both. Now, students will be asked to combine their graphing skills with their skills at solving projectile motion problems.

Stage 1-Desired Results

Standard(s):

- HS-PS2-1. Analyze data to support the claim that Newton's second law of motion is a mathematical model describing change in motion (the acceleration) of objects when acted on by a net force.

Aim/Essential Question:

- Why is projectile motion useful in the real world?

Understanding(s):

Students will understand that . . .

- A projectile is any object where the only force acting on it is gravity
- Projectile motion can be predicted using the kinematics equations

Content Objectives:

Students will be able to . . .

- find any of the missing values in the kinematics equations through knowledge of projectile motion and algebra
- create a position and velocity vs time graph for the situation given

Language Objectives:

ELD Level 1-3 *Students will be able to . . . in English*

- Explain in their own words what is going on in the word problem

ELD Level 4-5 *Students will be able to . . . in English*

- Collaborate with peers to solve the word problem

Key Vocabulary

- Projectile motion
- projectile
- vertical/horizontal
- velocity
- acceleration
- gravity
- graph/plot
- position

Stage 2-Assessment Evidence

Performance Task or Key Evidence

- competition of the lab activity

Key Criteria to measure Performance Task or Key Evidence

Stage 3- Learning Plan

Learning Activities:

Do Now/Bell Ringer/Opener: 5 min

Would you ever go squirrel suit jumping? GoPro: Graham Dickinson's Insane Wingsuit Flight - Front Helmet Cam 2 of 3 - YouTube

Learning Activity 1: 5 min

- Explain:
    - today's lesson will be about graphing once again.
    - Students will be given the entirety of the class period to read and understand the graphing prompt, do the calculations necessary, and then make up to three graphs.
    - Students may work together to solve the problem, but everyone must make their own graphs.

Learning Activity 2: 10 min

- Teacher-led demonstration
    - The teacher has a student read the problem out loud
    - The teacher goes through how to solve one aspect of the problem (i.e. how to find the vertical velocity of the imaginary huob at a certain time)

Learning activity 3: 30 min

Students finish the activity. Everyone must submit their own graphs. Graphs should have axes labels, a title, and an appropriate scale.

Multiple Intelligences Addressed:

☐ Linguistic
☐ Spatial
☐ Logical-Math
☐ Interpersonal
☐ Musical
☐Intrapersonal
☐Bodily-kinesthetic
☐Naturalistic

Student Grouping

☐ Whole Class
☐ Small Group
☐ Pairs
☐ Individual

Instructional Delivery Methods

☐ Teacher Modeling/Demonstration
☐ Cooperative Learning
☐ Independent Projects
☐ Lecture
☐ Centers
☐ Discussion
☐ Problem Solving

Accommodations	**Modifications**

Homework/Extension Activities:

No homework

Materials and Equipment Needed:

- Notebooks
- Chromebooks

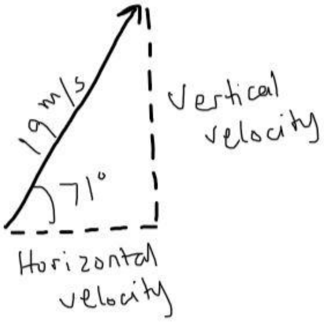
Adapted from Grant Wiggins and Jay McTighe-*Understanding by Design*

Goob is playing Florf on his home planet again. Remember, on his planet, gravity is -11 m/s^2. This time, Goob is zooming down the playing field, and he slaps the huob at 71° above the horizontal with a velocity of 19 m/s. Gib, who is on Goob's team, jumps straight up and catches the huob after it had been in the air for 2 seconds. Gib uses her wings to stay in the air, holding the huob, for 3 seconds. Then Gib sees Gub on the ground directly below her, so she drops the huob so Gub can catch it.

1. Make a vertical **velocity** vs time graph
2. Make a horizontal **position** vs time graph
3. (if time)Make a vertical position vs time graph

Playing Florf

The first graph I have to make is the vertical velocity vs time graph. So let me focus only on the vertical components of this problem before I worry about the horizontal components.
In order to find the vertical component, let me draw a triangle of the situation. Maybe that will help me figure out the trig.



I want to find the vertical velocity. Ok, that is the opposite side of the triangle. So I want to find the opposite, and I'm given the hypotenuse. Which trig function uses opposite and hypotenuse? The sine! Ok let me write down the equation for sine, and then plug in the numbers that I know.

$$\sin\theta = \frac{opp}{hyp}$$

$$\sin(71) = \frac{opp}{19\ m/s} \longrightarrow 19\sin(71) = opp$$

$$\boxed{17.96\ m/s = opp = \text{vertical velocity}}$$

Great! Now I have the initial vertical velocity. That is going to be the key to solving the rest of this problem.

The first thing the problem tells me is that after 2 seconds, the huob is caught by Gib. So it's probably important for me to know a few things about the huob at time = 2 seconds when I go to graph. Let me find the vertical velocity of the huob at 2 seconds.

$$V_f = V_i + at$$

$$V_f = 17.96\ m/s + (-11)(2\ s) \longrightarrow \boxed{V_f = -4.04\ m/s}$$

Woah! Wait a minute! The vertical velocity is negative? What does negative mean again? Oh right, it means downwards. So that means that the huob is moving downwards at 2 seconds. Ok. Let me think about it. The huob was going up at 17.96 m/s to start. Then it slowed down until it reached the maximum height, where the vertical velocity was 0. And then it started to accelerate back towards the ground. Now I get it: the huob *must* have reached the max height before time = 2 seconds, and now it's on it's way back down towards the ground. But where is it at 2 seconds? Let me calculate that. I have everything I need to use the first kinematics equation.

$$x_f = \frac{1}{2}at^2 + v_i t + x_i$$

In this case, the initial position is 0, because it started on the ground. The initial velocity is 17.96 m/s, because I'm only concerned with vertical components right now. I cannot mix the two up. The time I want to find the final position for is 2 seconds. And the acceleration on Florf is -11 m/s/s.

$$x_f = \frac{1}{2}(-11)(2)^2 + (17.96)(2) + 0$$

$$\boxed{x_f = 13.92 \text{ m}}$$

Awesome. So now I know the height at which Gib catches the huob. The reason I need that is because the next thing the problem says is that Gib drops the huob to Gub on the ground. And in order to graph velocity vs time, I should find the final velocity right before Gub catches it. If I have a height, I can calculate the time to fall, so let me do that really quick.

$$t_{fall} = \sqrt{\frac{2 \cdot \text{height}}{g}}$$

$$t_{fall} = \sqrt{\frac{2 \cdot 13.92}{11}} \longrightarrow t_{fall} = 1.59 \text{ s}$$

With this time to fall, I can now calculate the final velocity. Since I know it was dropped by Gib, then the initial velocity is zero.

$$V_f = V_i + at \longrightarrow V_f = 0 + (-11)(1.59 \text{ s})$$

$$\boxed{V_f = 17.49 \text{ m/s}}$$

Boy, that was a lot of work! So many steps. I need to take a nap. But first let me graph it. I am making a velocity vs time graph, which means that my slope is… I kind of forget. Oh right, the slope of a velocity vs time graph is the acceleration. Wait a minute… if the slope of the graph is the acceleration, and the acceleration is a constant -11 m/s/s, then I could've made this graph without doing almost *ANY* calculations!! All I would have had to find is the initial vertical velocity, since the rest of the graph would consist of lines with a slope of -11. Oh no! All that work for nothing! Well at least I got some good practice from it.

Name: Group Number: Period:

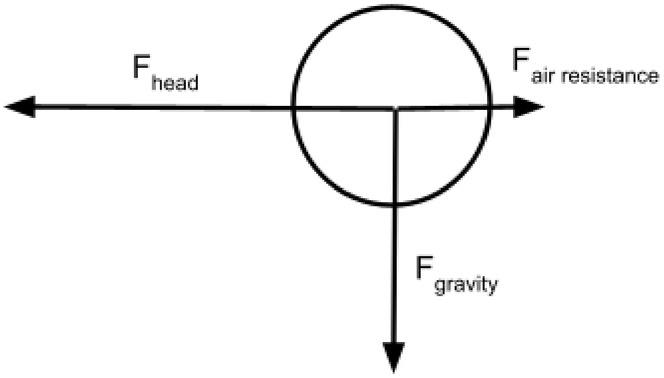
Imagine you are kicking a ball. The ball experiences a lot of forces. Think about these questions:

- **What do those forces look like?**
- **How large are they compared to each other?**
- **Which direction do they face?**

Directions: Work together with your partner to draw the **free body diagram** of the ball in the story.

- Draw your force vectors (arrows) the correct size for the force the ball experiences.
- Don't forget to label the force vectors!
- You and your partner should take turns reading the problems.

Example: I head the soccer ball to the left and there is air resistance



Different types of forces word bank:

force of gravity	**air resistance**
normal force	**force of friction**

These are examples, and there are other forces in the story!

Draw the forces acting on the ball when it's...

1. Not moving, just on the ground	2. Getting kicked straight up into the air →	3. In the air
4. Blown downwards by the wind	5. Blown to the right by the wind	6. Hitting the ground and bouncing straight up

7. Rolling on the ground to the right and slowing down due to friction	8. Not moving, just on the ground →	9. Pushed down when Ronaldo puts his foot on it
10. Ronaldo kicks the ball very hard at an angle of 20° above the ground towards the goal, and there is air resistance.	11. Hit the post with a horizontal velocity and bounce off.	12. Ronaldo punts the ball into outer space and the ball is floating in outer space (ignore gravity).

13. Remember Newton’s 1st law: “An object in motion stays in motion unless acted upon by an outside force” When the ball reaches outer space, is it still moving? Explain your answer.

Lesson Plan Title: Graphing f=ma

Teacher's Name: Simon Rees
Subject/Course: General physics
Unit: Force
Grade Level: 11/12

Overview of and Motivation for Lesson:
Students will learn the relationship between force and acceleration using graphing

Stage 1-Desired Results

Standard(s):

- HS-PS2-1. Analyze data to support the claim that Newton's second law of motion is a mathematical model describing change in motion (the acceleration) of objects when acted on by a net force.

Aim/Essential Question:

- How do forces make things move?

Understanding(s):

Students will understand that . . .

- Force and acceleration have a linear relationship
- The slope of a force vs acceleration graph is the mass of the object

Content Objectives:

Students will be able to . . .

- Make a nice graph using the data given
- Find the slope of the graph
- Interpret the slope of the graph to find that it equals the mass of the pilot

Language Objectives:

ELD Level 1-3 *Students will be able to . . . in English*

- Explain what "friction" is and which direction it acts

ELD Level 4-5 *Students will be able to . . . in English*

- Explain Newton's second law in their own words

Key Vocabulary

- Net force
- Free body diagram
- Newton's laws
- Air resistance
- Friction
- Gravity
- Normal force
- Motion
- Acceleration

Stage 2-Assessment Evidence

Performance Task or Key Evidence

- Completing the graph and answering some questions

Key Criteria to measure Performance Task or Key Evidence

Stage 3- Learning Plan

Learning Activities:

Do Now/Bell Ringer/Opener: 5 min

What is the fastest aircraft in the world, and what is the top speed?

Answer: SR-71 Blackbird, spy plane used during the Cold War. Has a top speed of 2,193 mph, or Mach 3+

https://www.youtube.com/watch?v=iKNS4DTj3io

See below for pic of John Stapp

Learning Activity 1: 10 min

Remind students of the equation for calculating force, F=ma, and of the graphing activity we did the other day with position, velocity, and acceleration.

What did all those graphs have in common? Write answers on the board

Could I ask you to make a graph of force vs time?

Could I ask you to make a graph of acceleration vs time?

Could I ask you to make a graph of force vs acceleration? Of course! In fact, that's what I'm going to do.

Remind people how to calculate slope.

This graph you will turn in at the end of class, so make sure you follow all the criteria.

Learning Activity 1: 20 min

Students get to work on the graphs. After 12 minutes, I tell students to get up and look at each other's graphs around the room, to get inspiration and see how other people are doing. Students get 15 minutes to make the graphs.

Learning Activity 1: 20 min

Once the graphs are completed, I remove the data table from the front of the room and I ask students to calculate the slope of their graph. They must tell me what the slope represents.

Show students the equation again: f=ma. In this case, since a is the x axis, then m is the slope.

Summary/Closing 3-5 min

Exit slip (on index card): what does the slope of a position vs time graph represent? What does the slope of a force vs acceleration graph represent?

Multiple Intelligences Addressed:

☐ Linguistic
☐ Spatial
☐ Logical-Math
☐ Interpersonal
☐ Musical
☐Intrapersonal
☐Bodily-kinesthetic
☐Naturalistic

Student Grouping

☐ Whole Class **☐ Small Group** ☐ Pairs ☐ Individual

Instructional Delivery Methods

☐ Teacher Modeling/Demonstration ☐ Lecture **☐ Discussion**
☐ Cooperative Learning ☐ Centers **☐ Problem Solving**
☐ Independent Projects

Accommodations	**Modifications**

Homework/Extension Activities:

No homework

Materials and Equipment Needed:

- Notebooks
- Chromebooks
- Pencils
- Graph paper

Adapted from Grant Wiggins and Jay McTighe-*Understanding by Design*

[Breaking Point: What's The Strongest G-Force Humans Can Tolerate? (medicaldaily.com)](https://www.medicaldaily.com)

Graph criteria: Title, axes labels, units, straight lines, appropriate scale (which means it fills up the page)
and most importantly *beautiful*

<u>Data for a pilot in a dogfight!</u> (The pilot weighs 77 kg)

g's (9.8 m/s^2)	Force (N)
0	0
5	3773
3	2264
4	3018
2	1509
1	754.6
6	4528

Lesson Plan Title: Learning How to Graph with Google Sheets

Teacher's Name: Simon Rees **Subject/Course:** General physics
Unit: Review **Grade Level:** 11/12

Overview of and Motivation for Lesson:
After coming back from the Thanksgiving break, the class will do a quick, one or two day lesson on graphing with Google sheets. This is to expose students to a resource for them, if they ever need to graph things for this class or another class in the future.

Stage 1-Desired Results

Standard(s):
- HS-PS2-1. Analyze data to support the claim that Newton's second law of motion is a mathematical model describing change in motion (the acceleration) of objects when acted on by a net force.

Aim/Essential Question:
- How do we use graphs to show trends in data?

Understanding(s):
Students will understand that . . .
- You can make all different types of graphs on Google sheets
- You can customize your graphs on sheets
- You can plot multiple sets of data on the same graph
- You can use sheets to find the slope of a trendline

Content Objectives:	**Language Objectives:**
Students will be able to . . . ● create graphs on Google sheets using data given to them	ELD Level 1-3 *Students will be able to . . . in English* ● ELD Level 4-5 *Students will be able to . . . in English* ●

Key Vocabulary
- graph/chart
- step
- axes
- error bars
- trendline

Stage 2-Assessment Evidence

Performance Task or Key Evidence
- completing the three graphs

Key Criteria to measure Performance Task or Key Evidence

Stage 3- Learning Plan

Learning Activities:
Do Now/Bell Ringer/Opener: 5 min
Will robots ever take over the world?

Learning Activity 1: 20 min
Go over some things in Google sheets:

- how to select data,
- how to insert charts,
- what the different tabs in the chart editor mean
- How to change the type of graph
- etc.

Learning Activity 2: 10 min
Students try to recreate the three graphs that are given to them using the data from the given spreadsheet. This is really intended to be a student-driven learning experience, so the teacher should be circulating the room and offering assistance, but students should be trying out all the options themselves.

Summary/Closing 3-5 min
Go over how Google sheets can be used to detect patterns in data and autofill cells

Multiple Intelligences Addressed:
☐ Linguistic ☐ **Logical-Math** ☐ Musical ☐Bodily-kinesthetic
☐ Spatial ☐ **Interpersonal** ☐**Intrapersonal** ☐Naturalistic

Student Grouping
☐ **Whole Class** ☐ **Small Group** ☐ Pairs ☐ Individual

Instructional Delivery Methods
☐ **Teacher Modeling/Demonstration** ☐ Lecture ☐ **Discussion**
☐ **Cooperative Learning** ☐ Centers ☐ **Problem Solving**
☐ Independent Projects

Accommodations	**Modifications**

Homework/Extension Activities:
No homework

Materials and Equipment Needed:

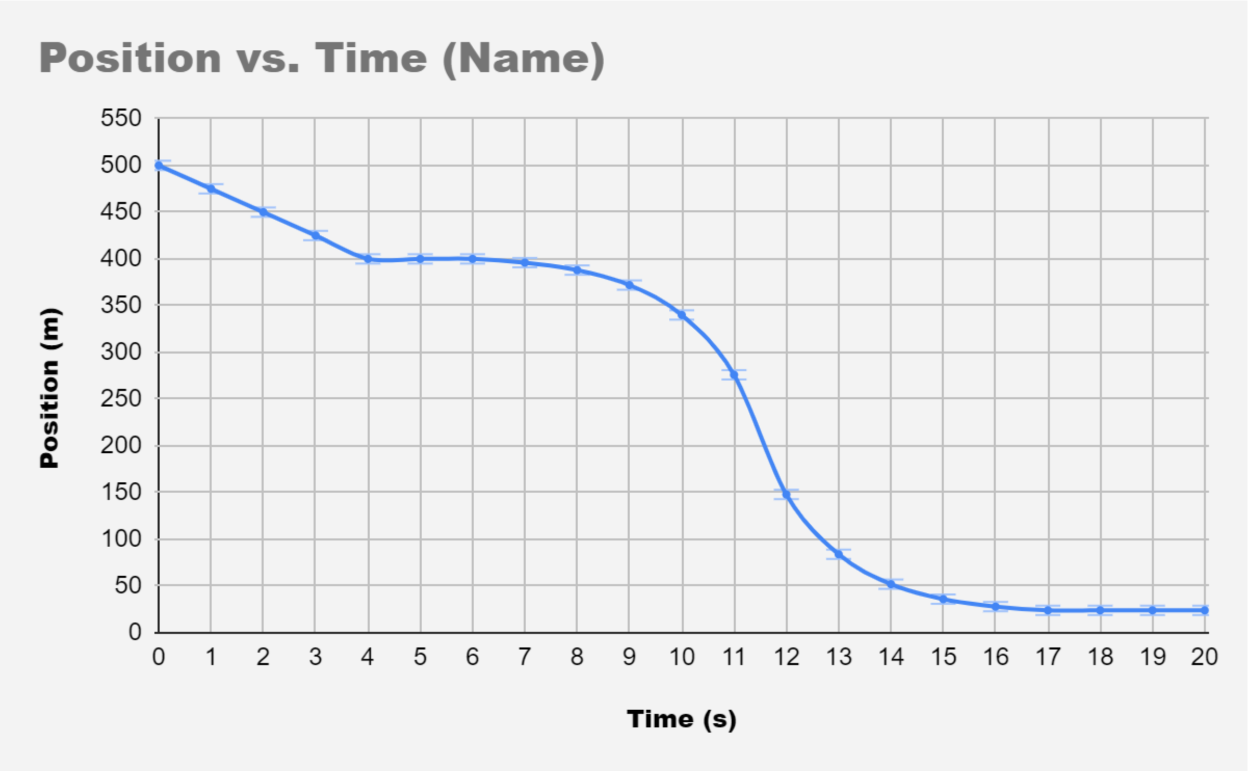
- Chromebooks

Learning to Graph with Google Sheets

The purpose of this activity is to expose you to graphing with Google Sheets so that if you ever need to create graphs/charts for this class or another class in the future, you'll have the knowledge of how to do so.

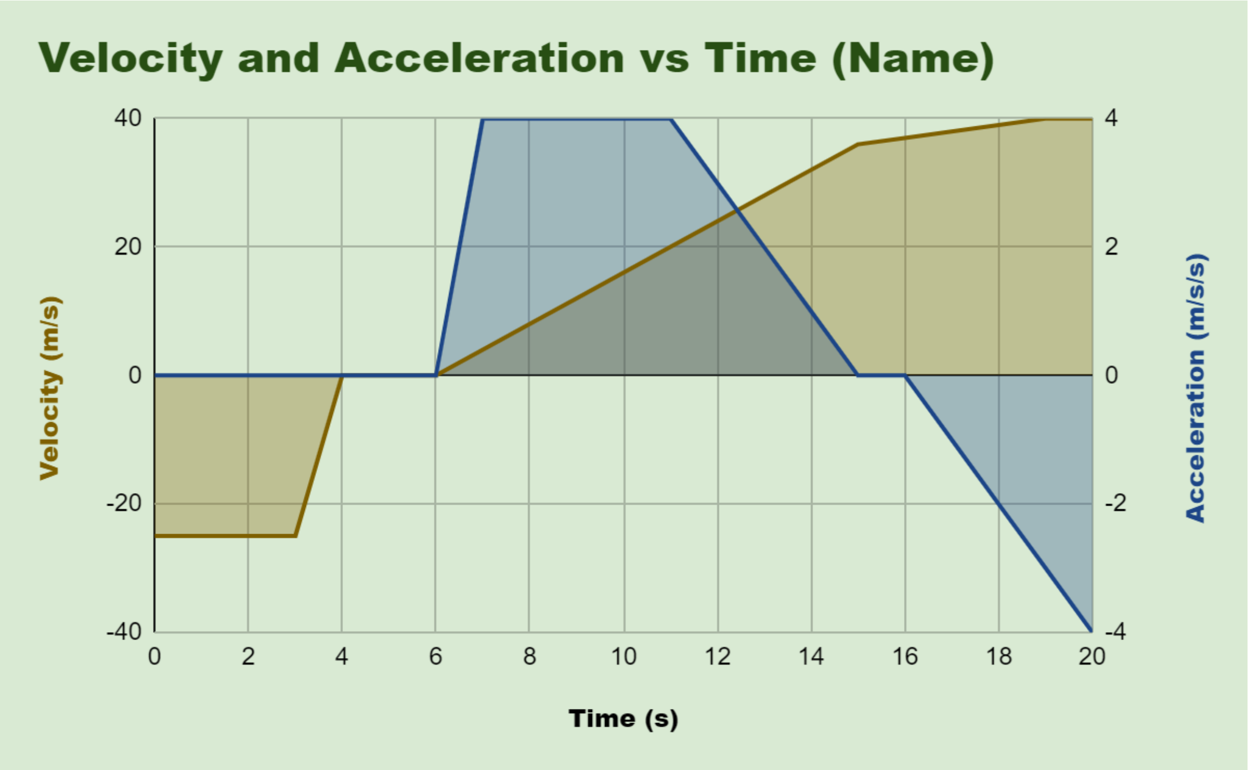
Please open up the spreadsheet that's posted in Google classroom. You will find some data on the spreadsheet about time, position, velocity, acceleration, and force. Please do the following:

1. Create a position vs time graph with the following characteristics
    a. Line chart
    b. Proper axes labels, including units
    c. The position axis goes from 0 to 550
    d. Smooth line
    e. Title and axes labels use "Wide" font
    f. The step on the time axis is every 1 second
    g. Error bars that are a constant 5 m
    h. Background color is light gray
    i. Your name in the title



Your graph here

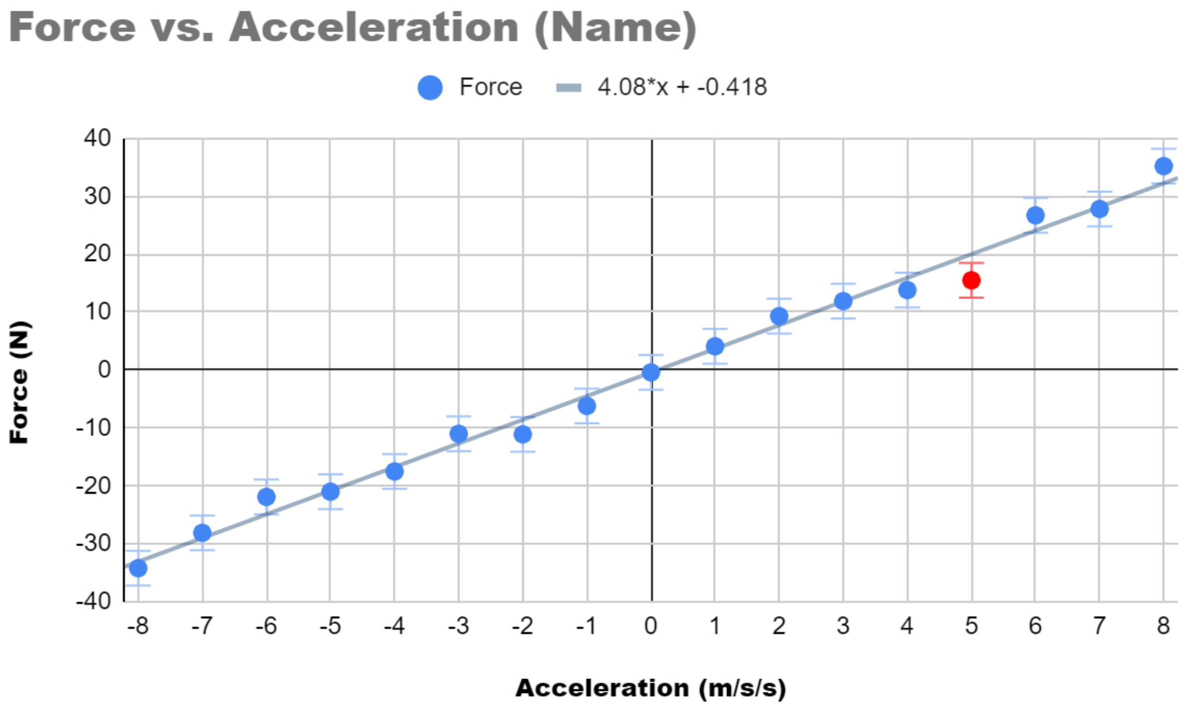
2. Create a chart that has both velocity vs time and acceleration vs time on the same graph with the following characteristics
    a. Area chart
    b. No legend; instead, two vertical axes labels, one for velocity and one for acceleration, including units
    c. Title and axes labels use “Wide” font. Title is dark green, velocity label is dark yellow, acceleration label is dark blue
    d. The step on the time axis is every 2 seconds
    e. Background color is light green
    f. Velocity line is dark yellow, acceleration line is dark blue
    g. Your name in the title



*Note: the velocity and acceleration data are not from the same motion

Your graph here

3. Create a force vs acceleration graph with the following characteristics
    a. Scatter chart
    b. Title and axes labels use "Wide" font
    c. Proper axes labels, including units
    d. Trendline, where the label is "use equation"
    e. Error bars that are a constant 3 N
    f. Formatted data point that falls outside the error, colored red
    g. The step on the time axis is every 1 second, and the step on the force axis is every 10 N
    h. The force axis goes from -40 N to 40 N
    i. Your name in the title



Your graph here

Graphing Centripetal Force on Google Sheets

With this exercise, you will see that by graphing the equation for centripetal force, you can see how each variable (mass, velocity, and radius) affects the force.

You will be responsible for <u>one</u> of the following three graphs:

1. **Force vs Mass (with linear trendline)**
2. **Force vs Velocity (with polynomial trendline)**
3. **Force vs Radius (with power series trendline)**

Base values:

- Mass = 1 kg (circle)
- Velocity = 1 m/s (star)
- Radius = 0.1 m (umbrella)

In order to create the data needed, you will need to change your specific variable and create a data table. For example, if I was changing the mass, I would calculate the centripetal force when the mass is 1 kg, 2 kg, 3 kg, etc.

You must get at least 12 data points. This means you need to do 12 calculations, for which you'll only change one number. Fill in the data table below with your 12 data points, and then copy the data into Google Sheets.

	Force (N)

Your graph must have the following:

- **A title with your name in it**
- **Axes labels with units**
- **A trendline**
- **A change in background color**

If you remember from when we practiced using Google sheets, the way that you make a chart is by selecting data in Google sheets, and then simply inserting a chart. You then customize the chart by changing the chart type. You can find the trendline option under “series”. The difference in this case is that you haven’t been given the data, you must get the data yourself using the equation for centripetal force.

Please insert your final graph here

1. What effect does mass have on centripetal force? In other words, as mass increases, what happens to the centripetal force?

2. What effect does velocity have on centripetal force? In other words, as velocity increases, what happens to the centripetal force?

3. What effect does radius have on centripetal force? In other words, as the radius increases, what happens to the centripetal force?

4. Which variable do you think has the greatest effect on centripetal force? EXPLAIN.