THE IMPORTANCE OF FORMATIVE ASSESSMENTS IN AP PHYSICS 1

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Chapter 1: Introduction

Problem Statement

AP Physics 1 is a course that prepares students for collegiate level STEM courses. AP Physics 1 Exam scores have proven to be a better indicator of collegiate level success in physics (and general STEM courses) than performance on other AP Physics exams. To me, this indicates that the AP Physics 1 curriculum, while challenging, is a better entryway into collegiate level STEM majors than AP Physics C. (Burkholder, 2021)

AP Physics 1 is less restrictive on students who are eligible to take the class, compared to AP Physics C, since it does not require previous calculus experience. (Burkholder, 2021) This means that more students who are traditionally disadvantaged and underrepresented are provided with an opportunity to take AP Physics 1, a collegiate level course, and break into careers that are disproportionately white and male. (Krakehl & Kelly, 2021)

However, AP Physics 1 is traditionally taught (and graded) in a manner that does not allow for students who need more structured educational approaches. It is often assumed that students in the course should be monitoring their own progress and preparing for summative exams without formative assessment feedback along the way. This provides significant disadvantages to students in schools and districts that are systemically held back. Students who need formative feedback are not innately incapable of learning and deserve the opportunity to learn. If we want to diversify the STEM fields, we as teachers need to find ways to provide all groups of students the opportunity to perform to the highest of their potential. (Krakehl & Kelly, 2021)

The nature of teaching AP Physics 1 is very time consuming. Providing feedback more than once a unit to students can be very daunting, maybe even impossible. The lack of structured immediate feedback assessments that correlate to the standards of AP Physics 1 can leave teachers underserving their students. If formative assessments become more sustainable, teachers can give more formative assessments, and save time overall.

Significance of Project

AP Physics 1 is an excellent course which encourages students to do go extremely deep with their understanding of physics concepts and their abilities to analyze and critique claims. Students are often hindered in this course due to either intimidation of the subject of physics or being left behind due to a lack of learning checkpoints along the way. (Stoeckel & Roehrig, 2021) My capstone project will allow teachers to identify the exact time and idea where students began to misconceive the ideas taught in the course and rectify those misconceptions as early as possible.

When students are given bountiful and timely feedback, their summative scores improve. (Nutbrown et al., 2016) More importantly, their confidence in the subject area increases and they feel more fondly about the course they are taking. By developing these sustainable formative assessments for AP Physics 1, more students will have access to a career path that they may not have had available to them previously. (Krakehl & Kelly, 2021)

Chapter 2: Literature Review

Part 1: Introduction

AP Physics 1 is a course that prepares students for collegiate level STEM courses. AP Physics 1 Exam scores have proven to be a better indicator of collegiate level success in physics (and general STEM courses) than performance on other AP Physics exams. To me, this indicates that the AP Physics 1 curriculum, while challenging, is a better entryway into collegiate level STEM majors than AP Physics C. (Burkholder, 2021)

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AP Physics 1 is an excellent course which encourages students to do go extremely deep with their understanding of physics concepts and their abilities to analyze and critique claims. Students are often hindered in this course due to either intimidation of the subject of physics or being left behind due to a lack of learning checkpoints along the way. (Stoeckel & Roehrig, 2021) My capstone project will allow teachers to identify the exact time and idea where students began to misconceive the ideas taught in the course and rectify those misconceptions as early as possible. When students are given bountiful and timely feedback, their summative scores improve. (Nutbrown et al., 2016) More importantly, their confidence in the subject area increases and they feel more fondly about the course they are taking. By developing these sustainable formative assessments for AP Physics 1, more students will have access to a career path that they may not have had available to them previously. (Krakehl & Kelly, 2021) According to Sadler & Tai (2001), having two years of high school physics better prepared students for success at a collegiate level. To open the doors to STEM for all, we first must open the doors to STEM success at the high school level for those at all schools.

Part 2: Theme 1: The Importance of Advanced Placement Physics 1 in Terms of Expanding STEM Majors and Careers to all Demographics

Advanced placement (AP) courses are designed to replace or supplement introductory level college level courses. AP Physics 1 is an algebra-based course and AP Physics C is a calculus-course. Both currently exist simultaneously and usually a secondary school offers one or the other. Burkholder (2021) studied the correlation between AP Physics experience and exam scores to other measures of physics performance. Prior research found that the binary of having or not having AP Physics experience correlated with introductory physics success at a rate not much higher than SAT or ACT math scores (Burkholder, 2021). The previous research did not differentiate between AP Physics 1 (AP1), which is algebra based, and AP Physics C (APC), which is calculus based, as a variable (Burkholder, 2021).

Burkholder's (2021) study compared the success of students who took AP1 to students who took APC in an introductory college physics course. The data regarding the binary choice of having taken AP physics or not showed statistical significance that students who took AP Physics scored higher in the introductory physics course than those who did not take AP Physics. They also showed that marginally significant data that support students that took APC performed better than those who took AP1. (Burkholder, 2021) Results showed that AP1 exam scores correlated with success in the introductory physics course while APC exam scores were not correlated with success. The AP course grades showed that students who took AP1 did not perform better than students who did not take AP Physics, but students who took APC did have a stronger course grade correlation than students who did not take AP Physics. (Burkholder, 2021) The study done by Burkholder (2021) was flawed in that it was conducted at one small and prestigious university. Expanding the sample to multiple colleges and demographics would give a better picture of the effectiveness of the different AP Physics courses.

Most resources for teaching AP Physics 1 are designed to help students perform and succeed at the college level since the course is designed to allow students to receive college credit through a summative exam score. However, AP Physics is a high school level course that is taken by high school students, who are in many cases, in need of differentiated lessons. The author studies the effect of adding tiered assignments for the varying level of students in her class. (Geddes, 2010)

Geddes's (2010) study does not dive into results of the lessons. This is a major flaw of the study and the article. However, the idea of tiering assignments for different students is very intriguing. Geddes's (2010) is correct in that AP Physics courses are courses for *high school* students and high school students do need and deserve structured and tiered lessons. It would be beneficial to conduct a study that compares how students who receive scaffolded lessons to students who do not.

Advanced science, technology, engineering, and math (STEM) course enrollment at the high school level is correlated to success at the university level. Based on the demographics of ethnicity, gender, and socioeconomic status, there are large inequities in the students who take these courses. At the collegiate level, many studies have been done about the intersectionality of STEM demographics and biases, but little has been done at the secondary level. Most female physicists have decided on a physics major prior to attending college. While in STEM fields across the board, females account for 57.3% of all bachelor's degrees, they only account for 20.4 % of physics bachelor's degrees. Black, Hispanic, and Native American students are also underrepresented in the category of physics bachelor's degrees. (Krakehl & Kelly, 2021) Females students had closed the enrollment gap in high school physics course in 2009, but there is still disparity in advanced physics courses, such as AP Physics 1. (Krakehl & Kelly, 2021)

Advanced Placement (AP) courses are offered disproportionately based on the school. Large schools with high populations offer many more AP courses than smaller schools and lower socioeconomic status schools. Students who are traditionally underrepresented in STEM courses are less likely to be enrolled in AP sciences than their counterparts. (Krakehl & Kelly, 2021) Black, Hispanic, and low socioeconomic students have AP passing rates that are one third as white and higher income students. (Krakehl & Kelly, 2021)

The research itself conducted by Krakehl & Kelly (2021) was quasiexperimental and involved observation of publicly accessible data disclosing the scores of the four different AP Physics course enrollment, scores, and the correlated student body demographics. (Krakehl & Kelly, 2021) All the data was compared to the U.S. public high school ethnic and gender breakdowns. The four courses' data was collected from AP Physics 1, AP Physics 2, AP Physics C Mechanics, and AP Physics C Electricity and Magnetism. Enrollment in courses and exam scores were correlated with the individual courses and demographic breakdowns and then compared to the national demographic breakdowns to see what disparities occurred. (Krakehl & Kelly, 2021)

Breakdowns of the exam scores for all fourteen groups were also represented. There are nuances to the scores but there are correlations between groups who were overrepresented and exam score success. The same groups that were found to be overrepresented tended to have exam scores higher than the world average and students in demographics who were underrepresented had scores below the world average. (Krakehl & Kelly, 2021)

AP Physics 1, which has the highest number of students enrolled, has the lowest average scores. Since the correlation between students being underrepresented and test scores applies here, it is logical that the underrepresented groups do not tend to go on to physics at the collegiate level. Most of the underrepresented groups did not pass the AP Physics 1 exam, four of the underrepresented groups did not average above a 2.0 on the exam. This cycle can continually discourage the currently underrepresented groups from continuing in physics. (Krakehl & Kelly, 2021)

The study by Krakehl & Kelly (2021) was done on a very large scale and accounted for data in an extremely logical way. A next step for this study would be to look at the same variables of success at a sampling of different high schools, categorizing traditionally "well off" schools and "worse off" schools to see where the socioeconomic correlation comes into play.

The field of physics is disproportional regarding gender; males are favored heavily at the professional level, as well as all academic levels. Women of color are even more underrepresented. Women experience a much lower rate of self-efficacy in physics classroom settings, which could be a cause of this problem. (Stoeckel & Roehrig, 2021)

The study conducted by Stoeckel & Roehrig (2021) compared qualitative assessments of the students' confidence in an AP Physics 1 class with quantitative test data. The qualitative assessments were used to sort students into two categories: high confidence and low confidence. The quantitative quizzes were used to separate students into high achieving and low achieving. The two sets were correlated to split all students into quadrants: Public (high achieving, high confidence), underestimating (high achieving, low confidence), unknown (low achieving, low confidence), and Overconfident (low achieving, high confidence). The results showed no correlation between the quadrant the student fell into and gender. (Stoeckel & Roehrig, 2021) Results showed that the girls were proportionately confident to the boys and that the students were very tuned into their abilities.

The study was limited in that students were only given the options of “boy” or “girl” as gender options which limited the studies ability to perceive gender. In addition, the study does not dive into students’ choices about what courses to enroll. Studying the decision making of males and females deciding whether or not to enroll in AP Physics, correlated to the students confidence levels would be an appropriate follow up study.

Crumley & DeJarnette (2022) looked to answer the question “can learning be measured in AP Science courses through writing prompts instead of traditional exams”? The authors designed his unit on the conservation of momentum to incorporate wide ranging writing skills instead of the traditional means of making students answer only AP exam style questions. Several guiding principles were put in place for the unit and the writing assessments. First, the writing generated by the students had to be authentically connected to the science content. Secondly, there had to be specific strategies put in place to support the students’ writing, such as class time dedicated to peer review, class time dedicated to writing, and structured writing prompts to guide responses. Lastly, the author believed that learning takes place in the most effective matter when diverse learners work together to collaborate. This could be achieved in person or online. (Crumley & DeJarnette, 2022)

Students were asked to share their feelings on the assignment and the results were varying. The author did not share the results of the written assignment but stated that all assignments were satisfactory. The traditional test given had had an average score of 82.5% in the previous two years and in the year the study was conducted the course score was an average of 84.0%. The author concluded that writing exercises for the unit certainly did not hinder the learning of the students, and possibly even helped. It is important to note that the study was conducted via remote learning and the prior test scores may not have been remote. (Crumley & DeJarnette, 2022)

The study by Crumley & DeJarnette (2022) had many flaws in the design. Remote assessments are very unreliable in data as a whole and using the remote learner test scores as evidence of learning is unreliable, however understandable based on the constraints of COVID-19 education. The preassessment data was not shared in the article so there is no way of knowing how the students did going into the study. In addition, the author did not share the scoring data from the actual written assignments that the students completed. Also, there was no information shared about the success of the students in prior units in the course. The study overall had solid intent, but the lack of quantitative data made it difficult to consider all variables.

AP Physics 1, while incredibly difficult, is the best physics course available regarding preparing students for collegiate physics (and STEM in general). This course needs more scaffolding and safety nets in terms of formative assessments so that groups that students who have been marginalized can take the course and receive the support they need. AP Physics 1 (Algebra Based) exam scores are correlated to success in collegiate level physics, whereas AP

Physics C (Calculus Based) exam scores do not correlate to collegiate success. (Burkholder, 2021) Underrepresented groups nationally are underrepresented within AP Physics courses (except for Asian students) and those groups also score worse on the AP Physics exams. (Krakehl & Kelly, 2021) Within the physics classrooms, there has been found to be no correlation between gender and confidence within the discipline. (Stoeckel & Roehrig, 2021)

Part 3: Theme 2: Formative Assessment to Improve Student Learning Within STEM Courses

2A: Teacher Attitude and Performance Towards Formative Assessment

Teachers in the United States have a wide variety of background and experience. This causes the delivery of curriculum to students to range wildly between states, schools, and teachers. Effectiveness of assessment is not only a factor of how the prompts are designed, but how and when they are utilized. The diversity of teachers, lessons, students, and classrooms makes the implementation of the researcher's assessment questions vital to researching the effectiveness of formative assessment. (Furtak et al., 2008)

The study defines *fidelity of implementation* as "a way of determining the alignment between implementation of a treatment and its original design". (Furtak et al., 2008) In order to measure the fidelity of implementation, the study focused on adherence to the planned pedagogy and the quality of delivery of the teachers. Adherence was measured by observing the implementation of all prompts, the sequence withing and between prompts, placement of discussions, and timing withing and between prompts. Quality of delivery was measured by observing the eliciting of student conceptions, the tracking and clustering of student conceptions, asking students to provide reasons for their explanations, students arguing ideas and evidence, and students providing evidence for their claims. (Furtak et al., 2008)

The teachers that scored higher on the quality of instruction measurements were found to produce students who improved their achievement more from pretest to posttest scores. The study found that teachers who followed the guide to teaching treatments the best produced more improvement in learning. It was also found that formative assessments must be designed to be administered and analyzed efficiently. The study suggests that due to practical constraints (mainly class time and teacher grading time) the most efficient formative assessments may be class discussions about how students supported their responses. (Furtak et al., 2008)

The study chose to only focus on how the experimental group of teachers-maintained fidelity to the plan since the objectives were to correlate lesson fidelity to formative assessments improvement in performance. However, it was stated in a previous paper that the control group performed better on the academic achievement scale. (Yin et al., 2008) It would be beneficial to know how the control group of teachers-maintained fidelity to the planned lessons and to see if that correlated to the success of the students. The study does not address the effectiveness of different specific types of formative assessments compared to each other. A logical follow up study would include a similar structure but include immediate feedback formative assessments to alleviate the need for class and grading time from the teachers.

Formative assessment has been proven to have positive results for students. Formative Assessment Classroom Techniques (FACTs) can give teachers very quick and easy data on how well a class is learning a subject. Student assessment in science needs to assess both a student's knowledge of science phenomenon and their ability to apply this knowledge to create inquiry in the world around them. FACTs have not been studied thoroughly in regards towards students' ability to create inquiry based on their knowledge of science phenomenon. (Ganajová et al., 2021)

The study conducted by Ganajová et al. (2021) consisted of both experimental and control groups. In both groups, the subjects of chemistry, biology, physics, mathematics, and informatics were all taught by the same teachers. In the control group, teachers did not use FACTs and in the experimental group, teachers did. Teachers used identical lessons and assignments in both groups, outside of the FACTs. (Ganajová et al., 2021)

The pretest indicated that neither control nor experimental groups had an advantage going into the study. All groups in the Slovakian study indicated that inquiry skills were low entering the study. The post test results found that there was a statistically significant improvement in the experimental groups. The study also found that using FACTs without the use of interventions still lead to an increase in performance in the experimental group. The demographical breakdowns also found that there was a greater improvement in inquiry ability in makes than in females. (Ganajová et al., 2021)

The next step for the study should be by subject area. The study did not breakdown the data based on content area of the teacher. Seeing these results based on the course would be beneficial. In addition, seeing a study in a homogenous group of students (all male or all female) would be beneficial to see if the effect of the opposite gender present can help hinder some of the productivity.

Based on the idea of constructivist theories, students take in new information and constantly compare it to known information and compare it for inconsistencies. The study conducted in this paper was based on this idea. (Ho et al., 2021) Teacher centered lecture style education is less effective than learner-centered instruction. This leads to teachers becoming facilitators and coaches in terms of education. With this student-centered approach, it is more critical to assess the learning of practical skills and knowledge required for careers and advancement in the topic, because the teacher does not directly control how the student intakes information. (Ho et al., 2021)

Short term programs (eight weeks or less) have been a trend in study abroad programs to encourage demographics traditionally underrepresented to participate. This includes many STEM majors who are often unable or unwilling to leave their home campuses for extended periods of time. There are questions about these shorter courses around the idea that they do not account for enough time for instructors to teach all the content necessary and give feedback to students along the way. Other research has indicated that short term programs are effective in teaching learners, but not as effective as traditional long-term programs (more than eight weeks). (Ho et al., 2021)

The results of the study done by Ho et al. (2021) showed that students benefited highly from the extra support given to students who performed low on assessments. All results were qualitative, but through surveys and instructor opinion it was shown that these extra sessions helped improve performance. (Ho et al., 2021) The instructors found the frequent assessment integral towards designing and repurposing class time based on the results of the assessments. (Ho et al., 2021)

This study is flawed in that it required massive resources, including students and staff. This would be uncreatable at a high school due to the lack of teacher assistants. A follow up study would be to select minimal assessments to give feedback, or portions of assessments, to see what effect the more streamlined formative assessments would have on student performance at the high school level.

Teachers need to embrace the idea that students need timely feedback on low stakes formative assessments to help confirm or deny students conceptions. It should not be assumed that all students in AP Physics (and other difficult AP STEM courses) do not need formative feedback because “they should have the ability to be successful without it”.

According to Dayal (2021), formative assessments are used to help teachers gauge learning during the learning process. Teachers emulate the styles of their favorite teachers; if they lack the data provided by formative assessments, the only students that will succeed are the students that learn in a similar manner to the original teachers. Lack of formative assessment narrows the window for students to truly learn and progress to their full capacities. The traditional Fijian means to mathematics education is heavily teacher centered and no formative assessments. The model of formative assessment used in the study has five formative actions. 1) Clarification of learning objectives and criteria with students, 2) designing of classroom activities that show evidence of what has been learned, 3) providing feedback to the learners that allows them to adjust accordingly, 4) the activation of students as resources for each other, and 5) empowering students in their own learning process. (Dayal, 2021)

Dayal (2021) looked to study the effect of preexisting ideas and attitudes of teachers towards formative assessment on student learning. The study found that the teachers’ beliefs about assessment and the role of education were consistent with their use of assessments. Gavin was shown to use the three tenants of the study as means to improve student learning. Jenny used formative assessments to categorize students but did not use the information learned from the assessments to improve learning. It was very evident that the teachers' prior beliefs towards teaching greatly affected the implementation of formative assessment and new ideas in the classroom. (Dayal, 2021)

The study lacked a control group or any student results. The aim of the study was to see how the prior attitudes and conceptions of the teachers affected how they implemented assessment, but it would be very helpful to see if one approach over the other produced better learning or a positive delta in learning. If one set of teachers had been observed that did not attend the phase two seminars, a control could have been found as to what the general idea of assessment was in the schools selected. The study would benefit from provided formative assessment as well to provide more of an equal comparison of the two groups.

Teachers need to embrace the idea that students need timely feedback on low stakes formative assessments to help confirm or deny students conceptions. Teachers' attitudes towards formative assessments have a large effect on their ability to properly administer formative assessment and adapt teaching based on the formative data. (Dayal, 2021) It should not be assumed that all students in AP Physics (and other difficult AP STEM courses) do not need formative feedback because "they should have the ability to be successful without it". Planning lessons around the data provided by formative assessments greatly improves student learning. (Ho et al., 2021) Formative assessment and feedback to students improves student inquiry and engagement. (Ganajová et al., 2021)

2B: Types of Formative Assessment and Effects on Learning

Technology advances dictate a constant adaptation of classroom teaching and assessment methods. New technology and software are being developed all the time in the realm of student assessment. Most agree that technology can be used to help students learn and obtain feedback. However, many students find technology to be stressful and burdensome in events of glitches and technological issues. Different users also prefer different types of learning software. Consistent feedback for learners is critical currently, but knowing which type of learning tools to use is paramount for teachers. (Grier et al., 2021)

The study focused on two different college education courses and used four different types of educational technology were used to create formative assessments that would correlate to the end of semester summative exam. The formative technologies used were Kahoot, Plickers, Socrative, and Google Forms. All the formative assessments were 5-10 questions and provided immediate feedback in some capacity. The assessments were all administered in class either during a lesson or at the conclusion of a lesson. At the conclusion of the course the students were all given a survey on a google form where they were asked to rank the technologies, respond to open ended questions, and provide their summative grades. (Grier et al., 2021)

The results show varying results, but the most definitive takeaway is that students and teachers prefer immediate feedback. There is no one software that is perfect for all students, but the four chosen in this study all provide some pros and cons to their use. Students prefer Plickers because it gives anonymous data to the class while giving individual feedback to the student answering and the teacher. Kahoot is simple, fun, and effective. Google Forms allows students to see the entire quiz at once and work at their own pace. Socrative is untimed and allows students to pace themselves while getting immediate feedback. Kahoot had the highest approval rating from both students and teachers. (Grier et al., 2021)

The study lacked a control group to compare quantitative data. Without a control group, it is impossible to know if the students' summative grades were improved by the formative assessments. If a follow up study was done, it would ideally be able to look at multiple years and multiple sections of identical courses. Comparing one year without the technologies to a year with.

(Nutbrown et al., 2016)

According to Nutbrown et al. (2016), feedback is the behavior of a teacher that is most related to achievement. Increasing the frequency with which feedback is given increases student performance. Surveys have indicated that students are most dissatisfied in courses with the clarity and timeliness of feedback. Previous research indicated that the following are the traits of feedback that are most important: Timeliness, the informativeness of the feedback, the consistency of the feedback, the clarity with which the feedback is communicated, the specificity of the errors being discussed in the feedback, and the usefulness to the teachers. (Nutbrown et al., 2016)

In the study performed by Nutbrown et al. (2016), the student survey indicated an appreciation for instant and automatic feedback, making it clear that they preferred manual feedback in conjunction with the automatic feedback. It was concluded that automatic feedback is helpful to both learning and student satisfaction. In addition, it was concluded that resubmissions were beneficial to learning. However, it was also determined that automatic feedback cannot be the only feedback students received throughout the learning process; manual feedback from teachers is also needed. (Nutbrown et al., 2016)

A follow up study could address the concept of automatic feedback across varying disciplines. This study only focused on a specific computer science course. Studies showing similar experiments conducted across a varying range of disciplines would benefit educators and confirm the findings of this study. A proposed new study would gather a group of experienced teachers that teach higher level courses where automatic feedback is appropriate. The courses would need to be identical to the previous year to provide a control group. Explicitly, this would be helpful in classes where there is often an explicit answer that can easily have an automated feedback system that is applicable to the students' initial responses.

Students are proven to learn and perform more when they form deep connections with the content as opposed to surface level rote memorization of facts. This is especially true in mathematical and scientific fields. Introductory science and math courses have many different ideas and concepts that need to be connected. When students are overwhelmed, they learn on the surface more frequently as a coping mechanism. (Law et al., 2020)

Student performance and learning become worse when they are disengaged. Students are more likely to become disengaged in an online environment because they need to actively choose to become engaged, while face-to-face students must actively choose to become disengaged. Students taking online courses are also more likely to drop the course entirely due to lack of personal connection. (Law et al., 2020)

Online exam proctoring services were adopted during the study done by Law et al. (2020), making it cost efficient for students to take all exams, regardless of remote or in person status. Formative assessments were attached to the online video modules that gave instant feedback. The study spanned many years and the addition online proctoring of assessments happened after 2018. Before and after this point were analyzed separately. 2018 serves as a separation of this study, in the “before” group, not all exams were proctored and there were no formative assessments in the video modules. The “after” group had these features. (Law et al., 2020)

There were no quantitative correlations found in the before and after group in terms student success or course completion. However, there was a large increase in engagement (online page views) once the mandatory proctored exams and quick check assessments were implemented. The study indicated that formative assessment grades decreased because of proctoring of assessments. (Law et al., 2020)

The study had many flaws; the biggest being the amount of variability of the study. The assessments of the precalculus course changed in the before and after implementation groups, which could drastically change the results. Also, the lack of attention to the differences in the structure of the chemistry and precalculus course make it hard to pull any real information from this study, other than less students were able to cheat when being proctored and students view videos more when they are held accountable for the material via formative quizzes. The study also fails to compare data to identical courses where students learned in person.

Future studies should be done on the structure of the formative assessments. What would happen if the embedded online formative assessments were tiered? Have an initial round that was more informative in what the student was not understanding (retake only missed questions) and follow up with a formative quiz that does not provide feedback on what the student got right and wrong.

According to Yin et al. (2008), most formative assessment studies have bene performed in laboratory settings and not in true classroom settings. Student learning is not just the development of new knowledge, but the ties between new knowledge and prior knowledge. Students often learn general principles at an early age but are not taught the “why” behind the concepts they are learning because they involve more advanced mathematical models. This causes students to fill in gaps in knowledge with misconceptions or over simplified models. These misconceptions lead to blocks in new learning unless a student is willing to conceptually change an idea or model they have created in their head. Creating these conceptual changes requires students to be motivated to learn new topics about ideas they feel they already have a grasp on. (Yin et al., 2008)

Summative assessments often create two problems. At the high end of a class, grades can cause an ego boost and on the low end of the spectrum can cause a lack of confidence that can spiral into other issues. The use of formative assessments prior to summative assessments are proposed to have mitigated many of these problems caused by using summative assessments only. Increase in learning motivation to learn and understand the material is one of the largest positive effects of formative assessments. (Yin et al., 2008)

The study found that the experimental group scored higher on the positive motivation assessment, but the control group scored higher on the academic achievement assessment. However, this data was determined to not be statistically significant, and it was concluded that there were no significant correlations between embedded formative assessment and motivation or achievement. It was determined that teacher and school backgrounds also did not significantly affect the results. The teachers that did show the best motivational and achievement results all carried four similar traits: 1) strong classroom management, 2) successful teaching strategies, and 3) effective formative assessment analysis and use. The study did not confirm that usage of formative assessments improves student achievement and motivation, but it did show that it is important to use formative assessments *effectively*. (Yin et al., 2008)

The study had many design flaws and gaps. There were many variables that were not considered in this study. Class size, school location, teacher experience, socioeconomic status, English language learners, and state requirements all varied in unaccounted for manors throughout the study. To study the effects more decisively, the researchers should find pairings of overwhelmingly similar classes and teachers that match in as many demographic categories as possible. The study could be redone by comparing one of the matching teachers in the experiment and one in the control.

According to Nieminen et al. (2021), formative assessments can be grouped into two categories, in the most general terms. They can be formal (written out quizzes, online questions, etc.), or they can be informal (group discussions, teacher asking question of student during lecture, etc.). Informal formative assessments have often been referred to as on-the-fly assessment. All the informal assessments refer to interactions between a teacher and student that are not totally planned beforehand. In general, in on-the-fly assessment can be viewed in four steps abbreviated as ERSU. Teacher elicits a question, student(s) respond, the teacher recognizes the response, and the teacher then uses the information to support the students and their learning. (Nieminen et al., 2021)

The case study done by Nieminen et al. (2021) took place in two seventh grade physics classrooms in an unnamed Finnish city. Pseudonyms were assigned to each teacher (Smith and Brown). Students were shown a video of a mirror covered in a cloth and asked to predict if two different students would be able to see a given object (billiard ball) based on their locations once the cloth was removed. After predictions, the cloth was removed, and students were asked to explain if their prediction and observation agree or differ. Lessons were videotaped to be analyzed. (Nieminen et al., 2021)

No formal conclusions were made about the effectiveness of either lesson taught due to a lack of measurability. There are many gaps in this study's process. The study did observe different purposes that teachers may use on-the-fly assessment for, but there was no measure of how successful they were. (Nieminen et al., 2021)

A follow-up study would be beneficial to give a pretest and posttest to measure student learning while counting the on-the-fly episodes and categorizing them. This could study the effectiveness of the different types of on-the-fly prompts and student achievement. It would also be beneficial to expand the number of teachers to a much larger number.

Cognitive psychological research shows humans process audio-visual data most effectively when both words and images are present in the same presentation. Multimedia use as formative assessment in classroom is becoming more and more common. Little research has been done studying the effect images in multimedia online assessments have on students' ability to correctly respond. (Gray et al., 2012)

Conceptest questions are questions specifically written to be answered by students in class settings by digitally selecting multiple choice answers based on their understanding of the principles being taught. If 75% of the students get a question correct, the teacher moves on. If less than 75% of the students get a correct answer, the students discuss in small groups and then answer the question again. (Gray et al., 2012) Regarding research question 1, the study found that students did not answer more efficiently on either text-only or illustrated questions. This confirms the hypothesis that mixing images and text on the same page effects new learning but does not help when assessing prior learning. This was true across all levels of ACT performing students as well. (Gray et al., 2012)

According to the study done by Gray et al. (2012), students did not answer more efficiently on either text-only or illustrated questions. This confirms the hypothesis that mixing images and text on the same page effects new learning but does not help when assessing prior learning. This was true across all levels of ACT performing students as well. (Gray et al., 2012)

In addition, study found that students who scored highest on the ACT's also scored highest on the Conceptest questions. This is most likely attributed to a student's overall level of preparedness to take an introductory earth science course correlation to a student's ability to do well on an ACT exam. The study also found that students who answered Conceptest questions correctly answered corresponding summative exam questions correctly at a higher rate. (Gray et al., 2012)

This study does not account for the confirmation that Conceptest questions provided for the students who answered correctly. Receiving initial positive feedback may cycle into future questions. A few follow-up studies could be done. The effects of having no Conceptest questions in a course on summative grades would be beneficial. Also, a study could be done on having ONLY text only based questions in the Conceptest question data bank vs. ONLY illustrated questions, vs a mix of both.

According to Curto Prieto et al. (2019), Kahoot is a technology that increases motivation through a game-like experience, while giving both teachers and students immediate feedback on the individual and the class. Previous studies have found that Kahoot helps students improve on the learning process, participation, and peer relationships. The immediate data given by Kahoot greatly stimulates class conversations and productivity. (Curto Prieto et al., 2019)

The purpose of Curto Prieto et al. (2019) in this study was to “analyze and compare the level of students’ satisfaction, in terms of their opinions about how the use of Kahoot has helped them in their learning process in science and mathematics.” They measure this through a series of Kahoots in varying appropriate classrooms. They then followed surveys administered through google classroom.

The results of the survey showed an overall level of high satisfaction with their learning process using Kahoot. The students showed that they felt they improved or greatly improved in all areas except for written/oral expression, creativity, and material access. Evidence showed that students were able to self-evaluate their learning more effectively (based on their opinion) than their previous experiences. (Curto Prieto et al., 2019)

Formative assessment is a key part of using flipped classrooms. Online formative assessment helps address many issues arisen using an asynchronous format, such as a flipped classroom. At the university level, online formative assessments have proven to be very effective in driving lessons for teachers. (Jeong et al., 2020)

Feedback from online assessments is also very important for the students. Feedback from online assessments provides data to students, but also can affect motivation. Self-determination theory states that the meta-analysis from online feedback can affect performance and motivation of students. (Jeong et al., 2020)

The study conducted by Jeong et al. (2020) looked to find the effects of online formative assessments in a slipped setting on performance and motivation in pre-service teachers (PST) in a university level STEM course. The study found that online formative assessments in a flipped classroom setting can increase PST's performance and motivation. The data showed students' views of society about science were the most improved in terms of motivation. In terms of enjoyment of science, students' anxiety about science decreased and enjoyment increased from pre-test to post-test. (Jeong et al., 2020)

This study has many gaps. The pre-test and post-test method seems inappropriate in terms of measuring performance of students learning a new subject. Scores are clearly going to increase throughout a course in this situation since they are being taught the material for the first time, regardless of the method of instruction. The motivational studies seem more relevant than the performance study. Students clearly felt more motivated in the flipped setting when receiving feedback from the online formative assessments and the online modules.

This study would be more beneficial with a control group to compare teaching methods; traditional vs flipped. An ideal study would observe a course that has been run for multiple years with lots of student data with the same teacher. If that teacher then switched to the flipped format in the study, ideally for multiple years to acquire more data, there would be significant evidence to support or deny the claim that the flipped format with online assessments improves performance.

When students do not prepare for laboratory activities, they can become cavalier with the experiment and reinforce misconceptions. Students also overwhelm their cognitive load by failing to prepare in advance for laboratory experiments and take on too much mentally in the laboratory activities. They then tend to focus on the short-term process of completing the mechanics of the experiment without thinking about the big ideas being demonstrated by the lab itself. (Shelby & Fralish, 2021)

Many skills and scenarios cannot be measured by traditional standardized tests. Digital simulations and games have become an increasingly larger means of engaging students in learning activities. However, it was found in most situations, the information about student learning acquired from these digital processes (referred to as process data) is rarely used by the educators assigning the simulation or game. (Cui et al., 2019)

There is not an explicit question asked by the researchers in the paper, but the assumed question based on the goal is below:

> "What are the effects of the implication of Bayesian Knowledge Tracing (BKT) and Dynamic Bayesian Networks (DBN) on the analysis of process data from a digital game-based assessment with the purpose of estimating students' probabilities of mastery of the skillset measured in the game?" (Cui et al., 2019)

Bayes' Theorem is a mathematical formula used to calculate conditional properties. (Joyce, 2021)

The study found that both BKT and DBN had some ability to analyze student process data in game-based assessments. The BKT model had more success, based on consistency and accuracy data. BKT is also more easily tested in these scenarios because it requires less sample data. (Cui et al., 2019)

The study lacked the comparison of data from the digital game to real world application (either traditional test or real-world simulation-based assessment). The study also failed to compare the sample group to any classes who did not use the game based formative assessment method. AA follow up experiment using the Bayes' Theorem predictions in the game-based learning unit should be compared to a traditional course. A matching assessment should be given to both groups at the end.

Pre-laboratory videos and quizzes have proven beneficial regarding forcing students to mentally prepare for the technical aspects of the laboratory activity, as well as the main concepts required to understand the experiment. Edpuzzle is a software that allows teachers to upload or embed existing videos and then require students to answer questions at certain times in the video. (Shelby & Fralish, 2021)

The study conducted by Shelby & Fralish (2021) looked to compare the use of Edpuzzle as a prelab quiz formative assessment to in class prelab formative assessment on paper. They used two previous years' results of in class paper quizzes as a control group. They then created at-home Edpuzzle quizzes with videos and identical prelab questions and observed prelab quiz grades for two more years. (Shelby & Fralish, 2021)

The Edpuzzle group was shown to perform better on 6 of the 7 pre-lab quizzes given throughout the semester. In 4 of the 7 quizzes, the students performed statistically significantly better, according to a t-test. The teachers also found the Edpuzzle beneficial in that they had results in advance and could foresee problems that would arise in the experiment based on results of the quiz. They could then use that information to quickly address the misconceptions or tweak a procedure. (Shelby & Fralish, 2021)

Overall, the students greatly preferred the Edpuzzle to the in-class quiz. In end-of-course surveys, students stated that the Edpuzzle helped to clarify misconceptions, were less intimidating, and improved confidence going into the laboratory. (Shelby & Fralish, 2021)

This study is flawed in that it only measured success on the pre-lab quizzes but did not account for the success of the actual lab itself. The study should have included percent error or percent yield for the students performing the experiments in both groups. This would show some sort of measurement of did the Edpuzzle prepare students for the laboratory better than the in-class quiz. Pre-lab quiz grades alone could have improved for a variety of reasons. A matching study should be done in which the control group and experimental groups both report a percent error or some sort of product that measures their success in the experiment.

Varying types of formative assessment should be used in different situations. Students need both immediate feedback assessments (online auto graded multiple choice) as well as feedback on open ended questions that comes from a human. Immediate feedback formative assessment built into lessons greatly increases student motivation and improves summative performance. (Yin et al., 2008) and (Nutbrown et al., 2016) Kahoot is a highly effective form of in class formative assessment which provides immediate feedback and has a very high approval rate with students. (Curto Prieto et al., 2019) The environment in which students take online formative assessments effects results. (Gray et al., 2012) Students appreciate immediate feedback formative assessment, but also require feedback from the teacher directly. (Law et al., 2020) In addition, according to Akiri et al. (2021), “all teachers selected standardized tests with open and closed ended questions, regardless of seniority.” This indicates that students need to be assessed in varying formats to prepare for standardized tests.

2C: Peer Assessment as a Form of Feedback on Formative Assessment

According to Ketonen et al. (2020), formative assessment is any gathering of information that allows teachers to adapt to meet student needs. Almost any activity can be used as a form of formative assessment, including peer assessment (PA). The effects PA as formative assessment is under researched at the secondary level. The study focuses on PA at the secondary levels to fill this gap. (Ketonen et al., 2020)

Students at the secondary level have been found to have weak feedback skills. It has been found that having students reflect on the quality of previous PA helps them generate better constructive feedback in the future. The level at which students can give feedback is correlated to the assessor’s reading and writing levels. (Ketonen et al., 2020)

Providing feedback can be equally as beneficial as receiving feedback. Having students engage with the criteria for which they will be graded themselves improves their ability to meet those criteria. A minority of students revised and improved their work when only receiving PA, but four out of five students revised and improved their work when both giving and receiving PA. (Ketonen et al., 2020) Overall, it was found that students who 1) put effort into their own work, 2) receive constructive feedback, 3) provide constructive feedback, and 4) use the PA to revise their final product benefit greatly from PA. (Ketonen et al., 2020)

This study had gaps in that it only looked at one small sample without a control. This study would benefit from looking at the same assignment results from years past without PA. To follow up on this study, conducting a study on the effects of similar peer assessment on other types of assignments, like free response questions and not just lab reports.

Peer assessment is a difficult task that is only worthwhile if done properly. Peer assessment can provide more feedback than a single teacher is capable of. All research on peer assessment indicated that it is only worthwhile if students can produce reliable and valid ratings. (Patchan et al., 2018)

While appropriate peer review is proven to be as helpful as teacher feedback, many students do not think that their peers can provide reliable feedback. To produce more frequent appropriate feedback, there are requirements put in place to assure valid responses. Minimum comment length, public exposure of feedback, teacher monitoring, author ratings of reviewers, automated evaluation of comments, and training on comment helpfulness are all processes through which peer reviewers can be held accountable for the feedback they give. (Patchan et al., 2018)

According to Patchan et al. (2018) students that perceived they were being rated on both conditions and students in the group that perceived they were only being reviewed on helpfulness had higher consistency ratings that those students who perceived they were rated on consistency ratings only. Almost all students provided the minimum number of comments, regardless of group. However, those in the perceived category and the perceived comments only group provided longer comments. The perceived both group and perceived comments only group scored higher on the features of their feedback than the ratings only group. All three groups scored the same in the perceived helpfulness by the author scores. (Patchan et al., 2018)

This study did not focus at all on the effect the feedback had on the improvement of the final paper. In a future study, it would be beneficial to see the correlation between proper peer review and the actual improvement of the produced grades. Also, this only focused on lab report writing. Focusing a peer review process on other types of assessments (free response and multiple-choice problems) would be beneficial.

The process of self-grading and peer-grading (SPG) is a useful formative assessment and source of feedback. SPG has grown in popularity as a zeitgeist has shifted from a model of assessment *of* learning to a model of assessment *for* learning. SPG is theorized to help students better understand assessment criteria, and in turn, develop clearer concepts of the assessed material. (Sanchez et al., 2017)

The results of the study conducted by Sanchez et al., found that SPG as a type of formative assessment improved performance on summative assessments over classes that did not use SPG as a formative assessment. The most conclusive result of the study showed that the use of SPG as a formative assessment improved test performance on matching concepts. There were few studies incorporated that did not provide SPG training and/or scaffolding, so the effect of training and scaffolding is inconclusive, however probable that training and scaffolding helps improve student feedback in SPG. When comparing self-graded scores to teacher scores, it was found that students inflated their grades slightly vs. the scores a teacher would give. When comparing peer-graded assignments to teacher grades, the grades were almost identical. (Sanchez et al., 2017)

The study was limited to data provided by previous research. The study lacked a focus on any STEM specific criteria, which was part of the hypothesis. A follow up study that would be beneficial would include conducting a study with three separate groups: 1) self-graders only, 2) peer-grade only, and 3) teacher grade only on formative assessments. Another follow up study would look at the effect of anonymous peer grading vs non-anonymous peer grading to see the effect of knowing the student who was being assigned a grade.

The study by Reinholz (2016) embraces the use of the assessment cycle. The assessment cycle flows from 1) task engagement, into 2) peer analysis, 3) feedback provision, 4) feedback reception, 5) peer conferencing, 6) revision, and finally back to a new task engagement. Task engagement is where students engage in some wort of prompt from the teacher (a writing prompt or question usually). Peer analysis involves a peer making some sort of judgement or critique to assign a grade or give constructive feedback. Feedback provision involves the reviewer describing their findings to the reviewee. Feedback reception is the reviewee's reflection on the reviewer's critique. Peer conferencing is students discussing the feedback of both feedback provision and feedback reception. Revision is the reviewee's use of their obtained perspective from both being a reviewee and reviewer to fix their product. The purpose of this study is to evaluate this cycle's effectiveness on student learning. The study took three different focuses, one on peer-assisted review (PAR), one calibrated peer review (CPR), and one on development of understanding of learning (DUAL). (Reinholz, 2016)

The results of the PAR study showed little difference in scores between the experimental and control groups. The CPR study found large improvements in CPR scores over control groups for multiple choice questions and negligible improvements on essay questions. The students in the experimental group of the DUAL study received negligibly lower scores on their lab reports, but 96% of the students surveyed expressed that marking the exemplars improved their understanding of the assignment. (Reinholz, 2016)

The study would benefit from a long ranging study. Students may have been overwhelmed in the short term in being asked to drastically change their writing and analysis style in one course or assignment. A study comparing a particular major in a university over past years compared to a new cohort that spans all four years in the university with the assessment-cycle implemented would be beneficial.

Peer grading is flawed in that it has consistency and validity concerns. However, these concerns also arise when students are graded by instructors. Students usually struggle to self-grade consistently and accurately, for obvious reasons. Learning the process of peer-grading may help students develop their ability to assess themselves. (Sridharan et al., 2019)

The results of Sridharan et al. (2019) showed that students could peer-grade with reasonable accuracy and consistency when the peer-grading does *not* affect the final grade (formative process). However, it was also found that students are unable to avoid grade inflation and show an inability to differentiate reporting in under contributing and overcontributing peers. Students also did not differentiate peer-grading between equal contributor students and over contributing students, showing a bias against students who “hog” all the workloads. (Sridharan et al., 2019) Overall, peer-grading works for formative assignments, not summative assignments.

The study showed gaps in that there was no individual measurement of learning. All these projects could show a small group of students learning all the material. Another set of data that would have been useful is to correlate the student's overall performance to a summative test that would measure the same learning outcomes.

Role, Audience, Format, and Topic (RAFT) assignments are creative writing prompts that allow students to be creative while being formatively assessed. (Dani et al., 2018) RAFT assessments force the student to look at something simple boring and simple, such as a graph of position versus time, and create a story about what is happening. This can be another quick assessment type used to formally assess on the fly. (Dani et al., 2018)

Proper peer grading is beneficial to student learning in that it: a) teaches students how they will be graded, b) provides needed timely feedback to students, and c) promotes sustainability for the teacher since it reduces their grading load. Students who put thought and purpose into peer graded assignments improve their summative assessment scores. (Ketonen et al., 2020), (Sanchez et al., 2017) Peer grading is more effective than self-grading, when each is done individually. (Sridharan et al., 2019) Students provide the best peer review feedback when they perceive that they are being graded on the helpfulness of their feedback. (Patchan et al., 2018)

Part 4: Conclusion

Science classes are by nature a place of trial and error. Students need to be able to state the way they understand concepts and receive timely confirmation of accurate views or adjustments to views that are skewed from reality. Without timely feedback, students can waste significant time attempting to use concepts that they misperceive. It is critical to find ways to give near immediate feedback for students. Students greatly appreciate fast feedback and feel that it leads to improved student learning. (Nutbrown et al., 2016)

AP Physics 1, while incredibly difficult, is the best physics course available regarding preparing students for collegiate physics (and STEM in general). This course needs more scaffolding and safety nets in terms of formative assessments so that groups that students who have been marginalized can take the course and receive the support they need. AP Physics 1 (Algebra Based) exam scores are correlated to success in collegiate level physics, whereas AP Physics C (Calculus Based) exam scores do not correlate to collegiate success. (Burkholder, 2021) Underrepresented groups nationally are underrepresented within AP Physics courses (except for Asian students) and those groups also score worse on the AP Physics exams. (Krakehl & Kelly, 2021) With these facts in mind, I choose to focus my capstone project on AP Physics 1 since it is an excellent experience for students that will prepare for them for the rigors of college level STEM courses. The assessments generated in my project will make success more accessible to students of all demographics.

Teachers need to embrace the idea that students need timely feedback on low stakes formative assessments to help confirm or deny students conceptions. It should not be assumed that all students in AP Physics (and other difficult AP STEM courses) do not need formative feedback because “they should have the ability to be successful without it”. Teachers' attitudes towards formative assessments have a large effect on their ability to properly administer formative assessment and adapt teaching based on the formative data. (Dayal, 2021) Planning lessons around the data provided by formative assessments greatly improves student learning. (Ho et al., 2021)

Varying types of formative assessment should be used in different situations. Students need both immediate feedback assessments (online auto graded multiple choice) as well as feedback on open ended questions that comes from a human. Immediate feedback formative assessment built into lessons greatly increases student motivation and improves summative performance. (Yin et al., 2008) and (Nutbrown et al., 2016) Kahoot is a highly effective form of in class formative assessment which provides immediate feedback and has a very high approval rate with students. (Curto Prieto et al., 2019) The environment in which students take online formative assessments effects results. (Gray et al., 2012)

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Chapter 3: Guide to Capstone Project

This section will walk through the purpose and reasoning behind the creation of each resource. All of these resources are available in full in the appendixes below. The resources are encouraged to be used to help teachers who are looking to broaden the demographics of students who can participate in AP Physics 1 and more collegiate level STEM courses.

Formative Assessments Correlated to AP Physics 1 Learning Standards (Appendix A)

In this section, there are seventeen different tables. Each table includes specific learning objectives and essential knowledge from the AP Physics 1 course and exam description. Below these sections are two sets of assessment questions, correlated to the learning objectives. One set is multiple choice questions along with explanations of the correct answers. The second set of assessment questions are free response questions, along with example answers that highlight what is expected in an appropriate response.

The multiple-choice assessments are designed to be used in a digital format (such as Kahoot or Google Forms) for instant feedback to the teacher and student. Ideally, these assessments would be given during or immediately following a lecture on the essential knowledge in that section of the curriculum but can be given as homework if time is not permitting. The multiple-choice assessments are ideal for catching misconceptions and a lack of understanding of the content early in the process. These can be used to redesign lessons on the fly, or to analyze between lessons to reframe topics that the students are struggling with. The free response questions are designed to be used later in the unit to allow students to demonstrate their learning by connecting to real world examples.

Most questions and assessments that currently exist for AP Physics 1 are designed to mimic AP exam questions and tie to multiple learning objectives and many different pieces for essential knowledge. This makes it very difficult for teachers to identify exactly where a student is becoming confused and what part of the curriculum they need to help the student with. Research shows that students in lower socioeconomic school districts are less likely to have success in AP Physics 1 or future college level STEM courses. If teachers in these districts have access to resources like these assessments, it will become easier for teachers to support students who have not had access to higher levels of STEM education in the past.

Laboratory Report Rubrics (Appendix B)

This rubric is supposed to provide a simple grading tool for teachers to give adequate feedback for students on their lab reports. Students will also be able to see exactly what is expected of them in each section of their lab reports so that they can write accordingly.

The secondary purpose of this rubric is to simplify the process of peer grading and review. Peer grading is an important part of the process for both the author and the grader. The author of the report can get critical feedback on their work prior to final submission. The grader gets valuable experience engaging with the rubric and expectations for lab reports as well. This also makes the formative feedback process more sustainable for teachers.

Peer Grading Expectations and Accountability Rubric (Appendix C)

This resource is to be used in conjunction with Appendix B, the lab report rubric. The peer grading process is only valuable when students take it seriously. Expectations have been laid out for the process students need to take to give adequate feedback while peer grading lab reports. More importantly, there is a rubric for accountability of the grader. Students will be awarded points for matching their evaluations of lab reports to the teachers scores. This motivated students to give honest and appropriate feedback to their peers.

Laboratory Experiment Objectives and Experiment Specific Questions (Appendix D)

This resource provides specific objectives for each experiment to be done throughout the year. The “intermediate goal” is a task goal the students must reach in order to obtain a constant value. That constant value must be used to predict a different value: the “competitive goal”. Students compete to achieve the lowest percent error in each experiment.

The lab specific questions are used to apply what they have learned to new ideas and topics. These questions should allow students to make connections, and in doing so, indicate to the teacher what level of understanding they have with the physics phenomena present in the experiment.

Chapter 4: Predictions for Use of Capstone Project

This project should be used to help teachers identify the needs of students in an incredibly rigorous course: AP Physics 1. AP courses are designed to be difficult and require a great deal of prior comprehension of content. While there is no way to help students immediately learn all content they needed prior to beginning the course, it is possible to simplify the process of identifying the needs of the learners.

Often, teachers are forced to let students sink or swim on their own within AP Physics 1. Identifying the specific needs of students can be extremely difficult from the resources that currently exist. This project should give teachers the ability to give assessments targeted to specific learning targets in a manner that is sustainable regarding their time.

This project can allow teachers to lower the walls that block many students from continuing into higher level STEM courses. Many students are given little chance to pursue careers in physics and engineering due to situations outside of their control, such as socioeconomic status, race, or gender. By allowing teachers to identify specific misconceptions quickly in class, teachers and students together can help overcome the obstacles involved in high level STEM courses, catch up to their peers, and have the doors of a like in STEM open to them.

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Appendix A: Formative Assessments Correlated to AP Physics 1 Learning Standards

Learning Objective	**Essential Knowledge**
1.1.A Describe a scalar or vector quantity using magnitude and direction, as appropriate. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	1.1.A.1 Scalars are quantities described by magnitude only; vectors are quantities described by both magnitude and direction. 1.1.A.2 Vectors can be visually modeled as arrows with appropriate direction and lengths proportional to their magnitude. 1.1.A.3 Distance and speed are examples of scalar quantities, while position, displacement, velocity, and acceleration are examples of vector quantities. i. Vectors are notated with an arrow above the symbol for that quantity. Relevant equation: $v = v_0 + at$ ii. Vector notation is not required for vector components along an axis. In one dimension, the sign of the component completely describes the direction of that component. Derived equation: $v_x = v_{0x} + a_x t$ (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)

1. Which of the following quantities is described by magnitude only?

A) Velocity

B) Acceleration

C) Distance

D) Force

Answer: C) Distance

Explanation: Distance is a scalar quantity as it is described by magnitude only. Velocity, acceleration, and force are vector quantities as they have both magnitude and direction.

2. Which of the following quantities is described by both magnitude and direction?

A) Speed

B) Mass

C) Temperature

D) Displacement

Answer:

D) Displacement

Explanation: Displacement is a vector quantity as it is described by both magnitude and direction. Speed, mass, and temperature are scalar quantities as they are described by magnitude only.

3. Which of the following best describes how vectors can be visually modeled?

A) As lines with different colors
B) As arrows with appropriate direction and lengths proportional to their magnitude
C) As circles with varying radii
D) As squares with different side lengths

Answer:

B) As arrows with appropriate direction and lengths proportional to their magnitude

Explanation: Vectors are often represented as arrows because arrows can indicate both the direction and magnitude of a vector. The length of the arrow represents the magnitude of the vector, while the direction of the arrow represents the direction of the vector.

4. What is the purpose of representing vectors as arrows?

A) To make them look visually appealing.

B) To indicate their magnitude only

C) To show their direction and magnitude

D) To represent their position in space

Answer:

C) To show their direction and magnitude

Explanation: Representing vectors as arrows allows us to visually depict both the direction and magnitude of the vector. This helps in understanding and analyzing vector quantities in various contexts, such as physics and mathematics.

5. Which of the following is an example of a scalar quantity?

A) Distance

B) Position

C) Velocity

D) Acceleration

Answer:

A) Distance

Explanation: Distance is a scalar quantity as it only has magnitude and no direction. It represents the total length of the path traveled.

6. Which of the following is an example of a vector quantity?

A) Distance
B) Position
C) Velocity
D) Speed

Answer Key:

C) Velocity

Explanation: Velocity requires a direction to be given (displacement per unit time), whereas speed does not require a direction component (distance per unit time).

Free Response Questions

1. Define a scalar quantity and provide an example.
2. Define a vector quantity and provide an example.
3. Explain how magnitude and direction are used to describe a vector quantity.
4. Give an example of a physical quantity that can be described as both a scalar and a vector, and explain why.
5. Describe a situation where knowing the direction of a vector quantity is crucial for understanding its physical meaning.

Answers:

1. Definition of a scalar quantity and an example:

- Scalar quantity: A quantity described by magnitude only.
- Example: Temperature (e.g., 25 ^{o}C).

2. Definition of a vector quantity and an example:

- Vector quantity: A quantity described by both magnitude and direction.
- Example: Velocity (e.g., 30 meters per second, east).

3. Explanation of how magnitude and direction describe a vector quantity:

Magnitude refers to the size or quantity of the vector, while direction specifies the path along which the vector is pointing. Both are necessary to fully describe a vector quantity.

4. Example of a physical quantity that can be described as both a scalar and a vector, along with an explanation:

- Example: Speed and Velocity
- Explanation: Speed is a scalar quantity as it describes only the magnitude of the motion, whereas velocity is a vector quantity as it describes both the magnitude and direction of the motion.

5. Description of a situation where knowing the direction of a vector quantity is crucial for understanding its physical meaning:

- Situation: Wind direction in meteorology.
- Explanation: Understanding the direction of the wind is essential for various purposes such as predicting weather patterns, understanding air circulation, and assessing potential impacts on various activities like sailing, flying, or construction

Learning Objective	**Essential Knowledge**
1.1.B Describe a vector sum in one dimension. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	1.1.B.1 When determining a vector sum in a given one-dimensional coordinate system, opposite directions are denoted by opposite signs. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)

1. When determining a vector sum in a given one-dimensional coordinate system, opposite directions are denoted by:

   A) The same sign
   B) Opposite signs
   C) No sign
   D) A different symbol

Answer: B) Opposite signs

Explanation: When determining a vector sum in a one-dimensional coordinate system, opposite directions are denoted by opposite signs.

2. In a one-dimensional coordinate system, if two vectors have the same magnitude but opposite directions, their vector sum will be:

   A) Zero
   B) The sum of their magnitudes
   C) The difference of their magnitudes
   D) The average of their magnitudes

Answer: A) Zero

Explanation: In a one-dimensional coordinate system, if two vectors have the same magnitude but opposite directions, their vector sum will be zero.

3. When adding vectors in a one-dimensional coordinate system, the magnitude of the resultant vector is equal to:

   A) The sum of the magnitudes of the individual vectors
   B) The difference of the magnitudes of the individual vectors
   C) The average of the magnitudes of the individual vectors
   D) The product of the magnitudes of the individual vectors

Answer: A) The sum of the magnitudes of the individual vectors

Explanation: When adding vectors in a one-dimensional coordinate system, the magnitude of the resultant vector is equal to the sum of the magnitudes of the individual vectors.

4. In a one-dimensional coordinate system, if two vectors have the same direction, their vector sum will be:

   A) Zero
   B) The sum of their magnitudes
   C) The difference of their magnitudes
   D) The average of their magnitudes

Answer: B) The sum of their magnitudes

Explanation: In a one-dimensional coordinate system, if two vectors have the same direction, their vector sum will be the sum of their magnitudes.

5. When adding vectors in a one-dimensional coordinate system, the direction of the resultant vector is determined by:

A) The direction of the first vector
B) The direction of the second vector
C) The sum of the directions of the individual vectors
D) The difference of the directions of the individual vectors

Answer: C) The sum of the directions of the individual vectors

Explanation: When adding vectors in a one-dimensional coordinate system, the direction of the resultant vector is determined by the sum of the directions of the individual vectors.

Free Response Questions

1. Consider two vectors, A and B, in one dimension. Vector A has a magnitude of 5 units and is directed to the right. Vector B has a magnitude of 3 units and is directed to the left. Calculate the vector sum of A and B.
2. Explain the concept of vector subtraction in one dimension. How is it different from vector addition?

Answers

1. To calculate the vector sum of A and B in one dimension:

Vector A: 5 units to the right

Vector B: 3 units to the left

- Given the direction convention, the vector B will be taken as negative. Therefore, the vector sum of A and B will be:

A + B = 5 - 3 = 2 units to the right.

2. Explanation of vector subtraction in one dimension:

- Vector subtraction in one dimension is the process of finding the resulting vector when one vector is subtracted from another. In this case, we treat the direction of the subtracted vector as opposite to its original direction. This is different from vector addition, where we simply add the magnitudes of the vectors and account for their directions by using appropriate signs.

Learning Objective	**Essential Knowledge**
1.2.A Describe a change in an object's position. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	1.2.A.1 When using the object model, the size, shape, and internal configuration are ignored. The object may be treated as a single point with extensive properties such as mass and charge. 1.2.A.2 Displacement is the change in an object's position. Relevant equation: $\Delta x = x - x_0$ (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)
Multiple Choice Questions (Instant Feedback)	
1.When using the object model, which of the following aspects are ignored? A) Size and shape B) Internal configuration C) Mass and charge D) All of the above Answer Key:	

D)All of the above

Description: When using the object model, all aspects including size, shape, and internal configuration are ignored. The object is treated as a single point.

2. Which of the following statements accurately describes displacement?

A) Displacement is the total distance traveled by an object.
B) Displacement is the speed at which an object moves.
C) Displacement is the change in an object's position.
D) Displacement is the force acting on an object.

Answer Key:

C) Displacement is the change in an object's position.

Description: Displacement refers to the change in an object's position, not the total distance traveled or the speed at which it moves.

3. What is the relevant equation for calculating displacement?

A) Displacement = Distance / Time
B) Displacement = Velocity x Time
C) Displacement = Acceleration x Time

D) Displacement = Mass x Acceleration

Answer Key:

B) Displacement = Velocity x Time

Description: The relevant equation for calculating displacement is Displacement = Velocity x Time. This equation considers the object’s velocity and the time it takes to travel.

Free Response Questions

1. Describe a change in an object's position and explain the factors that may have caused this change. Use specific examples to support your answer.
2. Consider a scenario where an object is initially at rest and then starts moving. Explain the concept of acceleration and how it relates to the change in the object's position. Provide an example to illustrate your explanation.
3. Imagine a situation where an object is moving in a straight line with a constant velocity. Discuss the forces acting on the object and explain why the object continues to move at a constant velocity. Provide a real-life example to support your explanation.

Answers:

1. Change in position: The movement of an object from one location to another. Factors causing change: External forces such as applied force, gravity, friction, or an internal force generated by the object itself. Example: A car moving from one city to another

due to the application of a driving force or an apple falling from a tree due to the gravitational force.

2. Explanation of acceleration in the context of an object initially at rest and then starting to move, with an example: Acceleration concept: Acceleration refers to the rate of change of velocity of an object over time. Example: A car starting from rest and gradually increasing its speed. The acceleration is the change in the car's velocity over time as it gains speed.

3. In the absence of external forces like friction or air resistance, the object experiences no net force. Explanation: With no net force acting, there is no change in the object's velocity, leading to constant velocity. Example: A satellite moving in a straight line in space without any significant external forces acting on it. The absence of significant gravitational or other forces allows the satellite to maintain a constant velocity.

Learning Objective	**Essential Knowledge**
1.2.B Describe the average velocity and acceleration of an object. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	1.2.B.1 Averages of velocity and acceleration are calculated considering the initial and final states of an object over an interval of time. 1.2.B.2 Average velocity is the displacement of an object divided by the interval of time in which that displacement occurs. Relevant equation: $v_{avg} = \frac{\Delta x}{\Delta t}$ 1.2.B.3 Average acceleration is the change in velocity divided by the interval of time in which that change in velocity occurs. Relevant equation: $a_{avg} = \frac{\Delta v}{\Delta t}$ 1.2.B.4 An object is accelerating if the magnitude and/or direction of the object's velocity are changing.

	1.2.B.5 Calculating average velocity or average acceleration over a very small time-interval yields a value that is very close to the instantaneous velocity or instantaneous acceleration. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)

1. Which statement accurately describes how averages of velocity and acceleration are calculated considering the initial and final states of an object over an interval of time?

A) The average velocity is calculated by dividing the change in position by the change in time, while the average acceleration is calculated by dividing the change in velocity by the change in time.

B) The average velocity is calculated by dividing the change in time by the change in position, while the average acceleration is calculated by dividing the change in time by the change in velocity.

C) The average velocity is calculated by dividing the change in position by the change in velocity, while the average acceleration is calculated by dividing the change in velocity by the change in position.

D) The average velocity is calculated by dividing the change in velocity by the change in position, while the average acceleration is calculated by dividing the change in position by the change in velocity.

Answer: A) The average velocity is calculated by dividing the change in position by the change in time, while the average acceleration is calculated by dividing the change in velocity by the change in time.

Explanation:

When calculating the average velocity, we divide the change in position by the change in time. This gives us the average rate at which the object's position changes over the given interval of time. On the other hand, when calculating the average acceleration, we divide the change in velocity by the change in time. This gives us the average rate at which the object's velocity changes over the given interval of time.

2. Which of the following statements accurately defines average velocity?

A) Average velocity is the total distance traveled by an object divided by the total time taken.
B) Average velocity is the displacement of an object divided by the interval of time in which that displacement occurs.
C) Average velocity is the speed of an object at a specific point in time.
D) Average velocity is the rate at which an object changes its position.

Answer: B) Average velocity is the displacement of an object divided by the interval of time in which that displacement occurs.

Explanation: Average velocity is a measure of how fast an object is changing its position over a specific time interval. It is calculated by dividing the displacement of the object by the time taken for that displacement to occur. Displacement refers to the change in position of an object, considering both the direction and magnitude of the change. Average velocity is different from average speed, which only considers the total distance traveled divided by the total time taken.

3. What is the definition of average acceleration?

A) The change in position divided by the interval of time
B) The change in velocity divided by the interval of time
C) The change in speed divided by the interval of time
D) The change in distance divided by the interval of time

Answer: B) The change in velocity divided by the interval of time

Explanation: Average acceleration is a measure of how quickly an object's velocity changes over a specific interval of time. It is calculated by dividing the change in velocity by the time interval in which that change occurs. Option A is incorrect because it refers to average velocity, which is the change in position divided by the interval of time. Option C is incorrect because it refers to average speed, which is the total distance traveled divided by the interval of time. Option D is incorrect because it refers to average distance, which is not a commonly used term in physics.

4. Which of the following statements accurately describes acceleration?

A) Acceleration occurs when an object is at rest.
B) Acceleration occurs when an object's velocity remains constant.
C) Acceleration occurs when an object's velocity changes in magnitude and/or direction.
D) Acceleration occurs when an object's position remains constant.

Answer: C) Acceleration occurs when an object's velocity changes in magnitude and/or direction.

Explanation: Acceleration is a measure of how an object's velocity changes over time. It can occur when the magnitude and/or direction of the object's velocity changes. Option A is incorrect because acceleration cannot occur when an object is at rest. Option B is incorrect because acceleration requires a change in velocity, not a constant velocity. Option D is incorrect because acceleration is not related to an object's position, but rather its velocity.

5. Which statement accurately describes the relationship between average velocity/acceleration and instantaneous velocity/acceleration?

A) Average velocity/acceleration is always equal to instantaneous velocity/acceleration.

B) Calculating average velocity/acceleration over a very small time-interval yields a value that is very close to the instantaneous velocity/acceleration.

C) Average velocity/acceleration is always greater than instantaneous velocity/acceleration.

D) Instantaneous velocity/acceleration is always equal to zero.

Answer: B) Calculating average velocity/acceleration over a very small time-interval yields a value that is very close to the instantaneous velocity/acceleration.

Explanation: The correct answer is B) Calculating average velocity/acceleration over a very small time-interval yields a value that is very close to the instantaneous velocity/acceleration.

Average velocity is calculated by dividing the change in displacement by the change in time. Similarly, average acceleration is calculated by dividing the change in velocity by the change in time. When the time interval becomes very small, the average velocity/acceleration approaches the instantaneous velocity/acceleration.

This concept is based on the idea that as the time interval approaches zero, the average velocity/acceleration becomes a better approximation of the instantaneous velocity/acceleration. However, it is important to note that the average and instantaneous values are not always exactly equal, especially in cases where there are significant changes in velocity/acceleration over the time interval.

Therefore, option B is the correct answer as it accurately describes the relationship between average velocity/acceleration and instantaneous velocity/acceleration.

Free Response Questions

1. Explain the concept of average velocity and how it differs from instantaneous velocity. Provide an example to illustrate your explanation.
2. Discuss the factors that can affect the average velocity of an object. How do these factors influence the overall motion of the object?
3. Define average acceleration and describe how it is related to velocity. Provide an example to support your explanation.

Answers

1. Explanation of average velocity and its difference from instantaneous velocity, with an example: Average velocity concept: Average velocity is the total displacement of an object divided by the total time taken. Difference from instantaneous velocity: Instantaneous velocity refers to the velocity of an object at a specific instant in time, whereas average velocity considers the overall displacement over a specific time interval. Example: A car travels from one city to another, and the average velocity is the total displacement divided by the total time taken, while the instantaneous velocity represents the car's velocity at any specific moment during the journey.
2. Discussion of the factors affecting the average velocity of an object and their influence on the overall motion: Factors affecting average velocity: External forces like friction, air resistance, applied force, and changes in direction can affect an object's average velocity. Influence on the overall motion: These factors can either increase or decrease the overall average velocity of the object, leading to changes in the speed or direction of the object's motion.
3. Definition of average acceleration and its relationship with velocity, with an example: Average acceleration concept: Average acceleration is the change in velocity divided by the time interval over which that change occurs. Relationship with velocity: Average acceleration indicates how quickly the velocity of an object changes over a specific period. Example: A car starting from rest and then gradually increasing its speed experiences average acceleration, which is the change in its velocity over the time it takes to achieve that change.

Learning Objective	**Essential Knowledge**
1.3.A Describe the position, velocity, and acceleration of an object using representations of that object's motion. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	1.3.A.1 Motion can be represented by motion diagrams, figures, graphs, equations, and narrative descriptions. 1.3.A.2 For constant acceleration, three kinematic equations can be used to describe instantaneous linear motion in one dimension. Relevant equations: $v_x = v_{x0} + a_x t$ $x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$ ${v_x}^2 = {v_{x0}}^2 + 2a_x (x - x_0)$ 1.3.A.3 Near the surface of Earth, the vertical acceleration caused by the force of gravity is downward, constant, and has a measured value approximately equal to a_g=g≈ 10 m/s2 1.3.A.4 Graphs of position, velocity, and acceleration as functions of time can be used to find the relationships between those quantities. i. An object's instantaneous velocity is the rate of change of the object's position, which is equal to the slope of a line tangent to a point on a graph of the object's position as a function of time.

	ii. An object's instantaneous acceleration is the rate of change of the object's velocity, which is equal to the slope of a line tangent to a point on a graph of the object's velocity as a function of time. iii. The displacement of an object during a time interval is equal to the area under the curve of a graph of the object's velocity as a function of time (i.e., the area bounded by the function and the horizontal axis for the appropriate interval). iv. The change in velocity of an object during a time interval is equal to the area under the curve of a graph of the acceleration of the object as a function of time. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)

1. Which of the following methods can be used to represent motion?

A) Motion diagrams

B) Figures

C) Graphs

D) Equations

E) All of the above

Answer: All of the above (E)

Explanation: Motion can be represented using various methods such as motion diagrams, figures, graphs, and equations. Each method provides a different perspective and allows for a comprehensive understanding of the motion being studied. Motion diagrams use a series of images to show the position of an object at different points in time. Figures can be used to visually represent the path or trajectory of an object. Graphs, such as position-time or velocity-time graphs, provide a visual representation of how the motion changes over time. Equations, such as those derived from kinematic principles, can be used to mathematically describe the motion. By utilizing these different methods, scientists and researchers can analyze and interpret motion in a variety of contexts.

2. Which of the following equations can be used to describe instantaneous linear motion in one dimension for constant acceleration?

A) $v = v_0 + at$

B) $\Delta x = v_0 t + 1/2at^2$

C) $v^2 = v_0^2 + 2a\,\Delta x$

D) All of the above

Answer Key: D) All of the above

Explanation: Equation A ($v = v_0 + at$) relates the final velocity (v) of an object to its initial velocity (v_0), acceleration (a), and time (t). Equation B ($s = v_0t + 1/2at^2$) relates the displacement (Δx) of an object to its initial velocity, time, and acceleration. Equation C ($v^2 = v_0^2 + 2a \Delta x$) relates the final velocity (v) of an object to its initial velocity, acceleration, and displacement. All three equations are valid and can be used to describe instantaneous linear motion in one dimension for constant acceleration.

3. Near the surface of Earth, the vertical acceleration caused by the force of gravity is:

A) Upward

B) Variable

C) Downward

D) Zero

Answer: C) Downward

Explanation: The vertical acceleration caused by the force of gravity near the surface of Earth is always directed downward. This acceleration is constant and has a measured value approximately equal to 10 m/s^2. It is important to note that this value may vary slightly depending on the location on Earth.

4. Which statement accurately describes an object's instantaneous velocity?

A) It is the rate of change of the object's position.

B) It is equal to the slope of a line tangent to a point on a graph of the object's position as a function of time.

C) It is the rate of change of the object's velocity.

D) It is equal to the area under the curve of a graph of the object's velocity as a function of time.

Answer: B) It is equal to the slope of a line tangent to a point on a graph of the object's position as a function of time.

5. What does the slope of a line tangent to a point on a graph of an object's velocity as a function of time represent?

A) The object's instantaneous velocity.

B) The object's instantaneous acceleration.

C) The object's displacement during a time interval.

D) The change in velocity of the object during a time interval.

Answer: A) The object's instantaneous velocity.

6. According to the given information, what does the area under the curve of a graph of an object's velocity as a function of time represent?

A) The object's instantaneous velocity.

B) The object's instantaneous acceleration.

C) The object's displacement during a time interval.

D) The change in velocity of the object during a time interval.

Answer: C) The object's displacement during a time interval

Free Response Questions

1. Consider an object moving along a straight line. Define the terms position, velocity, and acceleration in the context of the object's motion. Provide a brief explanation for each term.
2. A car is moving along a straight road. At time t=0 seconds, the car is at position x=10 meters. After 5 seconds, the car is at position x=30 meters. Calculate the average velocity of the car during this time interval.
3. An object is moving with a constant velocity of 5 m/s. Is the acceleration of the object zero? Justify your answer.
4. An object is moving with a constant acceleration of 2 m/s^2. If its initial velocity is 4 m/s, calculate its velocity after 6 seconds.
5. An object is moving with a constant acceleration of -9.8 m/s^2. If its initial velocity is 20 m/s, calculate its velocity after 4 seconds.

Answers

1. Definitions of position, velocity, and acceleration in the context of an object's motion:

- Position: The location of an object relative to a reference point, often denoted as x in one-dimensional motion.
- Velocity: The rate of change of an object's position over time, represented by v, and can be calculated as the derivative of the position function with respect to time.
- Acceleration: The rate of change of an object's velocity over time, denoted as a, and can be calculated as the derivative of the velocity function with respect to time.

2. Calculation of the average velocity of a car during a specific time interval: Average velocity (v_{avg}) = (Δx)/(Δt) = (30 meters - 10 meters) / (5 seconds - 0 seconds) = 20 meters / 5 seconds = 4 meters per second.
3. Explanation of whether the acceleration of an object is zero if it is moving with a constant velocity of 5 m/s: Yes, the acceleration of the object is zero if the object maintains a constant velocity. Acceleration is the rate of change of velocity, and if the velocity remains constant, there is no change in velocity over time.
4. Calculation of the velocity of an object with a constant acceleration of 2 m/s^2 after 6 seconds, given an initial velocity of 4 m/s: Final velocity (v_f) = Initial velocity (v_0) + (a Δt) = 4 m/s + (2 m/s^2 * 6 s) = 4 m/s + 12 m/s = 16 m/s.
5. Calculation of the velocity of an object with a constant acceleration of -9.8 m/s^2 after 4 seconds, given an initial velocity of 20 m/s: Final velocity (v_f) = Initial velocity (v_0) + (a Δt) = 20 m/s + (-9.8 m/s^2 × 4 s) = 20 m/s - 39.2 m/s = -19.2 m/s.

Learning Objective	**Essential Knowledge**
1.4.A Describe the reference frame of a given observer. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	1.4.A.1 The choice of reference frame will determine the direction and magnitude of quantities measured by an observer in that reference frame. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)

1. Which of the following statements best describes the concept of reference frames?

A) Reference frames are fixed points in space used to measure distances.

B) Reference frames are imaginary lines used to determine the direction of motion.

C) Reference frames are perspectives from which observations are made.

D) Reference frames are mathematical equations used to calculate velocities.

Answer: C) Reference frames are perspectives from which observations are made.

Explanation:

Reference frames are not fixed points or imaginary lines, nor are they mathematical equations. Instead, they are coordinate systems or perspectives from which observations of an object's position, motion, or interaction are made. Different reference frames can yield different descriptions of the same event, as they are relative to the observer's position and motion.

Understanding the concept of reference frames is crucial in accurately interpreting the dynamics and behaviors of objects in motion or interaction.

Free Response Questions

1. Explain the concept of a reference frame with respect to an observer witnessing a moving object. Choose a scenario to illustrate how the reference frame of the observer affects the perception of the object's motion. Include in your explanation how the observer's position and relative motion influence the description of the object's movement, and how the reference frame can be used to analyze the object's motion accurately.

Answers:

1. Explanation of a reference frame in the context of an observer witnessing a moving object, along with a scenario illustrating its effects on the perception of the object's motion:

   - The concept of a reference frame refers to a coordinate system used to describe the position and motion of objects. Observers use this frame to define the location of an event in both space and time. The choice of reference frame affects the perceived direction and magnitude of quantities, such as position, velocity, and acceleration, measured by the observer.

   - Scenario: Consider a moving train observed by a passenger inside and another person standing outside the train. For the passenger, the reference frame is the interior of the train, making the external landscape appear to be moving backward. In contrast, for the person standing outside the train, the reference frame is the stationary ground, causing the train to appear to be moving forward. The observer's position and relative motion influence the description of the train's movement, demonstrating how the reference frame can be used to accurately analyze the train's motion from different perspectives.

Learning Objective	**Essential Knowledge**
1.4.B Describe the motion of objects as measured by observers in different inertial reference frames. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	1.4.B.1 Measurements from a given reference frame may be converted to measurements from another reference frame. 1.4.B.2 The observed velocity of an object results from the combination of the object's velocity and the velocity of the observer's reference frame. i. Combining the motion of an object and the motion of an observer in a given reference frame involves the addition or subtraction of vectors. ii. The acceleration of any object is the same as measured from all inertial reference frames. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)

1. Which of the following statements is true regarding measurements from different reference frames?

A) Measurements from one reference frame cannot be converted to measurements from another reference frame.

B) Measurements from a given reference frame may be converted to measurements from another reference frame.

C) Measurements from different reference frames are always the same.

D) Measurements from different reference frames cannot be compared.

Answer: B) Measurements from a given reference frame may be converted to measurements from another reference frame.

Explanation: Measurements from a given reference frame may be converted to measurements from another reference frame. This statement aligns with the concept that measurements made in one reference frame can be translated or transformed to another reference frame, allowing for consistent analysis and comparison across different perspectives.

2. What determines the observed velocity of an object?

A) Only the object's velocity
B) Only the velocity of the observer's reference frame
C) The combination of the object's velocity and the velocity of the observer's reference frame
D) The acceleration of the object

Answer: C) The combination of the object's velocity and the velocity of the observer's reference frame.

Explanation: The observed velocity of an object results from the combination of the object's velocity and the velocity of the observer's reference frame. This implies that the relative motion between the observer and the object plays a crucial role in determining the observed velocity. The velocity of the object relative to the observer's reference frame is a combination of the two velocities.

3. Which of the following statements is true regarding the motion of an object and the motion of an observer in a given reference frame?

A) Combining the motion of an object and the motion of an observer involves multiplication of vectors.
B) Combining the motion of an object and the motion of an observer involves division of vectors.
C) Combining the motion of an object and the motion of an observer involves addition or subtraction of vectors.
D) The motion of an object and the motion of an observer in a given reference frame are always the same.

Answer: C) Combining the motion of an object and the motion of an observer in a given reference frame involves addition or subtraction of vectors.

Explanation: Combining the motion of an object and the motion of an observer in a given reference frame involves addition or subtraction of vectors. This emphasizes the principle that the combined motion of an object and an observer can be represented by adding or subtracting the respective velocities or motions to determine their overall motion relative to each other within the reference frame.

Free Response Questions

1. Explain the concept of an inertial reference frame and how it relates to the measurement of motion. Provide an example to support your explanation.
2. Discuss the implications of the theory of relativity on the perception of motion. How does the motion of objects appear differently to observers in different inertial reference frames? Use specific examples to illustrate your answer.

Answers:

1. Explanation of an inertial reference frame and its relation to the measurement of motion, along with an example: An inertial reference frame is a reference frame in which a body at rest remains at rest, and a body in motion continues to move at a constant velocity unless acted upon by an external force. This frame serves as a basis for understanding the laws of motion and mechanics. For example, a passenger in a smoothly moving train experiences the train as a stable reference frame, where objects inside the train appear to be at rest or in uniform motion unless influenced by external forces.
2. Discussion of the implications of the theory of relativity on the perception of motion and how the motion of objects appears differently to observers in different inertial reference frames, with specific examples: The theory of relativity states that the laws of physics are the same for all observers in any inertial reference frame. It introduces

the concept that time and space are relative and can appear differently to observers moving at different velocities. This theory implies that the perception of motion can vary depending on the observer's reference frame. For instance, the passage of time appears to differ for observers in motion relative to each other, and lengths may also appear contracted. The classic example is the twin paradox, where one twin travels at a high speed relative to the other, resulting in a noticeable difference in their aging processes.

Learning Objective	**Essential Knowledge**
1.5.A Describe the perpendicular components of a vector. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	1.5.A.1 Vectors can be mathematically modeled as the resultant of two perpendicular components. 1.5.A.2 Vectors can be resolved into components using a chosen coordinate system. 1.5.A.3 Vectors can be resolved into perpendicular components using trigonometric functions and relationships. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)

1. How can vectors be mathematically modeled?

A) By resolving them into components using a chosen coordinate system.

B) By resolving them into perpendicular components using trigonometric functions and relationships.

C) By taking the sum of two perpendicular components.

D) By taking the difference of two perpendicular components.

Answer: C) By taking the sum of two perpendicular components.

Explanation: Vectors can be mathematically modeled as the resultant of two perpendicular components. This involves taking the sum of these perpendicular components to determine the resultant vector. The process of modeling vectors in this manner allows for a clear understanding of how two perpendicular components contribute to the overall direction and magnitude of the vector.

2. What is the purpose of resolving vectors into components?

A) To determine the magnitude of the vector.
B) To determine the direction of the vector.
C) To simplify vector calculations.
D) To determine the resultant vector.

Answer: C) To simplify vector calculations.

Explanation: The purpose of resolving vectors into components is to simplify vector calculations. By breaking down a vector into its perpendicular components, complex vector operations can be simplified into more manageable and straightforward calculations, making it easier to work with vectors in various mathematical contexts.

3. Which method is used to resolve vectors into perpendicular components?

A) Trigonometric functions and relationships.
B) Chosen coordinate system.

C) Summing two perpendicular components.

D) Taking the difference of two perpendicular components.

Answer: A) Trigonometric functions and relationships.

Explanation: Trigonometric functions and relationships are used to resolve vectors into perpendicular components. By utilizing trigonometric functions such as sine and cosine, the magnitude and direction of the components of the vector can be determined relative to the chosen coordinate system. This method is crucial for accurately analyzing and manipulating vectors in various applications.

4. How can vectors be resolved into components using a chosen coordinate system?

A) By using trigonometric functions and relationships.

B) By summing two perpendicular components.

C) By taking the difference of two perpendicular components.

D) By projecting the vector onto the coordinate axes.

Answer: D) By projecting the vector onto the coordinate axes.

Explanation: Vectors can be resolved into components using a chosen coordinate system by projecting the vector onto the coordinate axes. By breaking down the vector along the x and y axes (or any chosen coordinate system), the perpendicular components of the vector can be determined. This approach aids in simplifying the analysis of vectors and facilitates calculations involving their components within the chosen coordinate system.

Free Response Questions

1. Define the term "perpendicular components" of a vector. Provide an example to illustrate your explanation.
2. Consider a vector A with magnitude 5 units and direction 30 degrees above the positive x-axis. Determine the perpendicular components of vector A.
3. Explain how you can find the perpendicular components of a vector when given its magnitude and direction.
4. A vector B has a magnitude of 8 units and its perpendicular component along the x-axis is 6 units. Determine the magnitude of the perpendicular component along the y-axis.
5. A vector C has a magnitude of 10 units and its perpendicular component along the y-axis is 8 units. Determine the magnitude of the perpendicular component along the x-axis.

Answers:

1. Definition of "perpendicular components" of a vector and an example: Perpendicular components of a vector refer to the parts of the vector that are oriented at right angles to each other. For instance, in a two-dimensional coordinate system, the horizontal and vertical components of a vector are perpendicular components. For example, the

horizontal and vertical forces acting on an object moving on an inclined plane are the perpendicular components of the gravitational force.

2. Determination of the perpendicular components of vector A: Given that vector A has a magnitude of 5 units and a direction of 30 degrees above the positive x-axis, the perpendicular components can be found using trigonometry. The horizontal component would be 5 * cos(30°) and the vertical component would be 5 * sin(30°).
3. Explanation of how to find the perpendicular components of a vector with given magnitude and direction: To find the perpendicular components of a vector with given magnitude and direction, you can use trigonometric functions such as sine and cosine. These functions help determine the horizontal and vertical components of the vector based on the given angle and magnitude.
4. Determination of the magnitude of the perpendicular component along the y-axis for vector B: If the perpendicular component along the x-axis is 6 units and the magnitude of vector B is 8 units, you can use the Pythagorean theorem to find the magnitude of the perpendicular component along the y-axis.
5. Determination of the magnitude of the perpendicular component along the x-axis for vector C: If the perpendicular component along the y-axis is 8 units and the magnitude of vector C is 10 units, you can use the Pythagorean theorem to find the magnitude of the perpendicular component along the x-axis.

Learning Objective	**Essential Knowledge**
1.5.B Describe the motion of an object moving in two dimensions. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	1.5.B.1 Motion in two dimensions can be analyzed using one-dimensional kinematic relationships if the motion is separated into components. 1.5.B.2 Projectile motion is a special case of two dimensional motion that has zero acceleration in one dimension and constant, nonzero acceleration in the second dimension. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)

1. Which of the following statements is true about motion in two dimensions?

A) Motion in two dimensions can only be analyzed using two-dimensional kinematic relationships.

B) Motion in two dimensions can be analyzed using one-dimensional kinematic relationships if the motion is separated into components.

C) Motion in two dimensions can only be analyzed using three-dimensional kinematic relationships.

D) Motion in two dimensions cannot be analyzed using kinematic relationships.

Answer: B) Motion in two dimensions can be analyzed using one-dimensional kinematic relationships if the motion is separated into components

Explanation: Motion in two dimensions can be analyzed using one-dimensional kinematic relationships if the motion is separated into components. This is because the components can be treated independently as separate one-dimensional motions, allowing the application of one-dimensional kinematic equations along each axis separately.

2. Which of the following statements is true about projectile motion?

A) Projectile motion has zero acceleration in both dimensions.
B) Projectile motion has zero acceleration in one dimension and constant, nonzero acceleration in the second dimension.
C) Projectile motion has constant, nonzero acceleration in both dimensions.
D) Projectile motion has varying acceleration in both dimensions.

Answer: B) Projectile motion has zero acceleration in one dimension and constant, nonzero acceleration in the second dimension.

Explanation: Projectile motion has zero acceleration in one dimension (horizontal axis) due to the absence of any force acting in that direction and constant, nonzero acceleration in the second dimension (vertical axis) due to the influence of gravity. This explains the curved trajectory of a projectile, where the horizontal velocity remains constant, and the vertical velocity changes due to the constant acceleration of gravity.

3. A ball is thrown horizontally off a cliff with an initial velocity of 20 m/s. Which of the following statements is true about the motion of the ball?

A) The ball will follow a curved path due to the acceleration of gravity.
B) The ball will follow a straight path due to the initial horizontal velocity.
C) The ball will follow a parabolic path due to the combined effects of horizontal and vertical motion.
D) The ball will follow a vertical path due to the acceleration of gravity.

Answer: C) The ball will follow a parabolic path due to the combined effects of horizontal and vertical motion.

Explanation: The ball will follow a parabolic path due to the combined effects of horizontal and vertical motion. As the ball is thrown horizontally, it has an initial horizontal velocity, and simultaneously, it experiences a downward acceleration due to gravity. The resulting motion combines these two effects, resulting in a parabolic path.

4. A car is traveling at a constant velocity of 30 m/s east. Which of the following statements is true about the car's motion?

A) The car is accelerating in the east direction.
B) The car is accelerating in the west direction.
C) The car is not accelerating.
D) The car's acceleration cannot be determined without additional information.

Answer: C) The car is not accelerating.

Explanation: The car is not accelerating. Constant velocity means the car's speed and direction are not changing over time. Since acceleration is the rate of change of velocity, the absence of any change in the car's velocity implies zero acceleration.

5. A projectile is launched at an angle of 45 degrees above the horizontal. Which of the following statements is true about the projectile's motion?

A) The projectile will reach its maximum height at the midpoint of its trajectory.
B) The projectile will reach its maximum height at the beginning of its trajectory.
C) The projectile will reach its maximum height at the end of its trajectory.
D) The projectile will not reach a maximum height.

Answer: A) The projectile will reach its maximum height at the midpoint of its trajectory.

Explanation: The projectile will reach its maximum height at the midpoint of its trajectory. In a symmetric projectile motion, the highest point is reached when the vertical component of the projectile's velocity becomes zero. In a 45-degree launch angle, the upward and downward components are equal at the peak, indicating the midpoint of the trajectory.

Free Response Questions

1. Consider a projectile launched at an angle of 45 degrees to the horizontal. Explain how the horizontal and vertical components of its velocity change throughout its motion. Provide a mathematical explanation to support your answer.
2. A ball is thrown horizontally off a cliff with an initial velocity of 20 m/s. The cliff is 50 meters high. Calculate the time it takes for the ball to hit the ground. Show all your work and include the appropriate equations.
3. A car is traveling at a constant speed of 30 m/s around a circular track with a radius of 100 meters. Explain why the car experiences acceleration even though its speed remains constant. Use appropriate physics concepts to support your answer.
4. A projectile is launched from the ground with an initial velocity of 50 m/s at an angle of 30 degrees above the horizontal. Determine the maximum height reached by the projectile. Show all your work and include the necessary equations.
5. A ball is thrown with an initial velocity of 15 m/s at an angle of 60 degrees above the horizontal. Calculate the range of the projectile. Show all your work and include the appropriate equations.

Answers:

1. Explanation of how the horizontal and vertical components of the projectile's velocity change throughout its motion, with a mathematical explanation: Throughout the projectile's motion, the horizontal component of velocity remains constant, as there is no force acting horizontally. The vertical component, however, changes due to the

constant acceleration of gravity. It decreases until reaching the highest point, where it becomes zero, and then increases downward. Mathematically, the horizontal velocity (v_x) remains constant, while the vertical velocity (v_y) changes according to $v_y = v_{0y} - gt$.

2. Calculation of the time taken for the ball to hit the ground after being thrown horizontally off a 50-meter high cliff: Given that the initial vertical velocity is 0 m/s and the acceleration due to gravity (g) is approximately 9.81 m/s/s, we can use the kinematic equation $\Delta y = v_{0y} t + \frac{1}{2} gt^2$ and solving for t.
3. Explanation of why the car experiences acceleration despite maintaining a constant speed, using appropriate physics concepts: The car experiences acceleration because it is changing direction as it moves along the circular track. Even though the speed remains constant, the direction is constantly changing, which is the definition of acceleration - a change in velocity. This change in velocity is due to the centripetal force, directed toward the center of the circular path.
4. Determination of the maximum height reached by the projectile launched from the ground with an initial velocity of 50 m/s at an angle of 30 degrees above the horizontal: The maximum height can be found using the kinematic equation for vertical motion. By using the initial vertical velocity, the angle of launch, and the acceleration due to gravity, we can determine the time it takes to reach the maximum height. The maximum height is then calculated using the formula $y_{max} = v_{0y}^2 / 2g$
5. Calculation of the range of the projectile thrown with an initial velocity of 15 m/s at an angle of 60 degrees above the horizontal: The range can be calculated using the

horizontal component of the initial velocity, the angle of launch, and the acceleration due to gravity. Using the formula for range, $R = \Delta x = v_x \Delta t$.

Learning Objective	**Essential Knowledge**
2.1.A Describe the properties and interactions of a system. 2.1.B Describe the location of a system's center of mass with respect to the system's constituent parts. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	2.1.A.1 System properties are determined by the interactions between objects within the system. 2.1.A.2 If the properties or interactions of the constituent objects within a system are not important in modeling the behavior of the macroscopic system, the system can itself be treated as a single object. 2.1.A.3 Systems may allow interactions between constituent parts of the system and the environment, which may result in the transfer of energy or mass. 2.1.A.4 Individual objects within a chosen system may behave differently from each other as well as from the system as a whole. 2.1.A.5 The internal structure of a system affects the analysis of that system. 2.1.A.6 As variables external to a system are changed, the system's substructure may change. 2.1.B.1 For systems with symmetrical mass distributions, the center of mass is located on lines of symmetry.

	2.1.B.2 The location of a system's center of mass along a given axis can be calculated using the equation $$x_{cm} = \frac{\Sigma m_i x_i}{\Sigma m_i}$$ 2.1.B.3 A system can be modeled as a singular object that is located at the system's center of mass. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)

1. Which statement best describes the properties of a system?

A) System properties are determined by the interactions between objects within the system.

B) The properties or interactions of the constituent objects within a system are not important in modeling the behavior of the macroscopic system.

C) Systems do not allow interactions between constituent parts and the environment.

D) Individual objects within a system always behave the same as the system.

Answer: A) System properties are determined by the interactions between objects within the system.

Explanation: System properties are determined by the interactions between objects within the system. This means that the behavior, characteristics, and properties of the system are a result of how the constituent objects interact and affect one another within the system, influencing the overall system's behavior and properties.

2. When can a system be treated as a single object?

A) When the properties or interactions of the constituent objects within a system are not important.
B) When the system has symmetrical mass distributions.
C) When the system's center of mass is located on lines of symmetry.
D) When the internal structure of a system affects the analysis of that system.

Answer: A) When the properties or interactions of the constituent objects within a system are not important.

Explanation: A system can be treated as a single object when the properties or interactions of the constituent objects within the system are not crucial in modeling the behavior of the macroscopic system. In such cases, the individual interactions or properties of the parts can be simplified or ignored, allowing the system to be represented and analyzed as a whole.

3. What can result from interactions between the constituent parts of a system and the environment?

A) Transfer of energy or mass.

B) No change in the system's properties.

C) Isolation of the system from the environment.

D) No interactions between the constituent parts and the environment.

Answer: A) Transfer of energy or mass.

Explanation: Interactions between the constituent parts of a system and the environment can result in the transfer of energy or mass. This highlights the concept that systems can exchange energy or mass with their surroundings, which is crucial in understanding how systems behave and evolve over time in response to external influences.

4. How does the internal structure of a system affect its analysis?

A) It does not affect the analysis of the system.

B) It determines the behavior of the system.

C) It may change as variables external to the system are changed.

D) It is irrelevant to the analysis of the system.

Answer: C) It may change as variables external to the system are changed.

Explanation: The internal structure of a system can affect its analysis, as it may change as variables external to the system are changed. This implies that the internal configuration, arrangement, or properties of the components within the system can be influenced or altered by changes in external factors, leading to variations in the system's behavior and structure.

Free Response Questions

1. Explain the concept of a system and provide examples of different types of systems.
2. Describe the properties of a system and how they can affect its behavior and interactions.
3. Explain the concept of center of mass and its significance in relation to a system's constituent parts.
4. Discuss the factors that can influence the location of a system's center of mass.
5. Provide an example of a real-world system and explain how understanding its center of mass can be useful in analyzing its behavior.

Answers:

1. Explanation of the concept of a system and examples of different types of systems: A system refers to a collection of interacting or interrelated entities that form a unified whole. Examples of different types of systems can include mechanical systems (e.g., a pendulum), biological systems (e.g., an ecosystem), and physical systems (e.g., a solar system).
2. Description of the properties of a system and their influence on behavior and interactions: The properties of a system, such as its internal structure, composition, and the interactions between its constituent parts, significantly affect its behavior and the way it interacts with its environment. These properties determine the system's response to external stimuli and its overall functioning.
3. Explanation of the concept of the center of mass and its significance in relation to a system's constituent parts: The center of mass refers to the point where the entire mass of a system can be considered to be concentrated. It is a crucial parameter that helps characterize the overall motion and behavior of a system, especially in the context of external forces acting on the system.
4. Discussion of the factors influencing the location of a system's center of mass: Several factors can influence the location of a system's center of mass, including the distribution of mass within the system, the relative positions of its constituent parts, and any external forces acting on the system. Changes in these factors can alter the center of mass and subsequently affect the system's overall behavior.

5. Example of a real-world system and an explanation of how understanding its center of mass can be useful in analyzing its behavior: One example could be a suspension bridge. Understanding the center of mass is crucial in ensuring the stability and safety of the bridge. By analyzing the distribution of mass and forces acting on the bridge, engineers can make informed decisions about its design and construction to maintain structural integrity and prevent potential failures.

Learning Objective	**Essential Knowledge**
2.2.A Describe a force as an interaction between two objects or systems. 2.2.B Describe the forces exerted on an object or system using a free-body diagram. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	2.2.A.1 Forces are vector quantities that describe the interactions between objects or systems. i. A force exerted on an object or system is always due to the interaction of that object with another object or system. ii. An object or system cannot exert a net force on itself. 2.2.A.2 Contact forces describe the interaction of an object or system touching another object or system and are macroscopic effects of interatomic electric forces. 2.2.B.1 Free-body diagrams are useful tools for visualizing forces being exerted on a single object or system and for determining the equations that represent a physical situation. 2.2.B.2 Thefree-body diagram of an object or system shows each of the forces exerted on the object by the environment. 2.2.B.3 Forces exerted on an object or system are represented as vectors originating from the representation of the center of mass, such as a dot. A system is treated as though all of its mass is located at the center of mass.

	2.2.B.4 A coordinate system with one axis parallel to the direction of acceleration of the object or system simplifies the translation from free body diagram to algebraic representation. For example, in a free-body diagram of an object on an inclined plane, it is useful to set one axis parallel to the surface of the incline. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)

1. What is a force, according to the essential knowledge provided?

   A) A scalar quantity that describes interactions between objects

   B) A vector quantity that describes interactions between objects

   C) An abstract concept with no physical significance

   D) A quantity that describes an object's state of motion

Answer: B) A vector quantity that describes interactions between objects

Explanation: A force is a vector quantity that describes interactions between objects. This definition emphasizes that forces have both magnitude and direction and act as a result of interactions between objects or systems.

2. According to the given information, what do contact forces describe? (Pick two)

A) Gravitational interactions between objects

B) Electrostatic interactions between objects of the atoms inside an object.

C) Interactions between objects at a distance

D) Interactions of objects touching each other

Answer: B and D

Explanation: Contact forces describe the interactions of objects touching each other and are also macroscopic effects of interatomic electric forces. This implies that contact forces involve interactions between objects at a distance and at the atomic level within an object.

3. What does a free-body diagram of an object or system represent?

A) Only external forces exerted on the object

B) Only internal forces within the object

C) Both external and internal forces on the object

D) Only gravitational forces on the object

Answer: A) Only external forces exerted on the object

Explanation: A free-body diagram of an object or system represents only the external forces exerted on the object. Internal forces within the object are not typically considered in free-body diagrams. This allows for a simplified analysis of the object's external forces and their effects on its motion.

4. How are forces exerted on an object or system represented in free-body diagrams?

   A) As arrows pointing toward the object's center of mass
   B) As arrows originating from the center of mass of the object
   C) As dots originating from the center of mass of the object
   D) As lines originating from any point within the object

Answer: B) As arrows originating from the center of mass of the object

Explanation: Forces exerted on an object or system are represented in free-body diagrams as arrows originating from the center of mass of the object. This representation helps visualize the direction and relative magnitude of the external forces acting on the object, providing a clear understanding of the forces' influences.

5. According to the essential knowledge provided, what kind of coordinate system simplifies the translation from a free-body diagram to an algebraic representation in the case of an object on an inclined plane?

   A) A polar coordinate system
   B) A spherical coordinate system
   C) A cylindrical coordinate system
   D) A coordinate system with one axis parallel to the surface of the incline

Answer: D) A coordinate system with one axis parallel to the surface of the incline

Explanation: A coordinate system with one axis parallel to the surface of the incline simplifies the translation from a free-body diagram to an algebraic representation in the case of an object on an inclined plane. This specific coordinate system allows for the easy separation of forces acting on the incline and those perpendicular to it, facilitating the analysis of the object's motion.

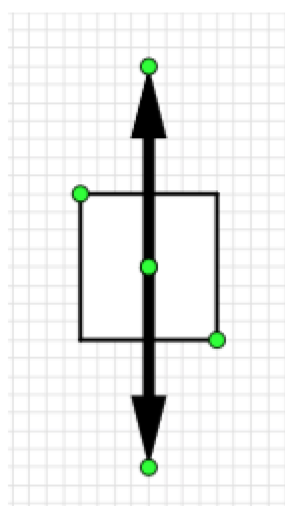
Free Response Questions

1. Explain the concept of a force in the context of interactions between two objects or systems. Provide an example to illustrate your explanation.
2. Draw a free-body diagram for a book lying on a table. Identify and label all the forces acting on the book and briefly describe each force.
3. In what ways do forces affect the motion of an object? Explain with reference to the concepts of balanced and unbalanced forces.
4. Choose a real-life scenario, and describe how multiple forces interact in that situation. Use a free-body diagram to illustrate your explanation.

5. Explain the significance of understanding forces and their interactions in the context of engineering design. Provide an example from everyday life where a grasp of these concepts is crucial in ensuring the functionality and safety of a product or structure.

Answers:

1. A force is a push or pull that acts upon an object as a result of its interaction with another object. For example, when you push a door, you exert a force on it, causing it to move. This interaction between your hand and the door demonstrates the concept of a force as an interaction between two objects.
2. The free-body diagram for a book lying on a table would include the following forces:
   - Weight (downward force due to gravity)
   - Normal force (upward force from the table supporting the book)



3. Forces can either change the motion of an object or maintain its state of motion. Balanced forces result in no net force, leading to no change in motion, whereas

unbalanced forces cause acceleration or deceleration of the object, depending on the direction of the net force.

4. Example scenario: A car moving on a straight road. Forces involved:
   - Driving force (forward force from the engine)
   - Frictional force (opposing the car's motion)
   - Air resistance (opposing the car's motion)
   - Weight (downward force due to gravity)
5. Understanding forces and their interactions is crucial in engineering design as it enables engineers to predict and control the behavior of structures and products. For example, in bridge construction, engineers must consider the forces acting on the bridge, such as tension, compression, and bending, to ensure its stability and safety.

Learning Objective	**Essential Knowledge**
2.3.A Describe the interaction of two objects using Newton's third law and a representation of paired forces exerted on each object. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	2.3.A.1 Newton's third law describes the interaction of two objects in terms of the paired forces that each exerts on the other. 2.3.A.2 Interactions between objects within a system (internal forces)do not influence the motion of a system's center of mass. 2.3.A.3 Tension is the macroscopic net result of forces that segments of a string, cable, chain, or similar system exert on each other in response to an external force. i. An ideal string has negligible mass and does not stretch when under tension. ii. The tension in an ideal string is the same at all points within the string. iii. In a string with nonnegligible mass, tension may not be the same at all points within the string. iv. An ideal pulley is a pulley that has negligible mass and rotates about an axle through its center of mass with negligible friction.

	(*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

<u>Multiple Choice Questions (Instant Feedback)</u>

1. How does Newton's third law describe the interaction of two objects?

   A) In terms of the acceleration of the objects.

   B) In terms of the velocity of the objects.

   C) In terms of the paired forces each exerts on the other.

   D) In terms of the distance between the objects.

Answer: C) In terms of the paired forces each exerts on the other

Explanation: Newton's third law describes the interaction of two objects in terms of the paired forces that each exerts on the other. This principle emphasizes that for every action, there is an equal and opposite reaction, highlighting the balanced nature of forces in an interaction.

2. What is the influence of internal forces on the motion of a system's center of mass, according to the given information?

   A) They accelerate the center of mass.

   B) They decelerate the center of mass.

   C) They do not influence the motion of the center of mass.

   D) They reverse the direction of the center of mass.

Answer: C) They do not influence the motion of the center of mass

Explanation: According to the given information, internal forces within a system do not influence the motion of the system's center of mass. This implies that the motions resulting from internal forces cancel each other out in terms of the system's overall movement, allowing the center of mass to move as if no internal forces were acting.

3. What is tension?

    A) The result of compression within a system.
    B) The force exerted by an object on a surface.
    C) The net result of forces that segments of a string exert on each other.
    D) The energy stored in a stretched string.

Answer: C) The net result of forces that segments of a string exert on each other

Explanation: Tension is defined as the net result of forces that segments of a string exert on each other. This emphasizes the idea that tension arises from the internal interactions within the string or cable, resulting in the net force transmitted along the length of the string.

4. Which of the following statements is true for an ideal string, as per the provided information?

    A) It has significant mass and stretches under tension.
    B) It has negligible mass and does not stretch under tension.
    C) It has significant mass and does not stretch under tension.

D) It has negligible mass and stretches under tension.

Answer: B) It has negligible mass and does not stretch under tension

Explanation: An ideal string is characterized as having negligible mass and not stretching under tension. This suggests that in ideal conditions, a string does not contribute to the overall mass of the system and remains taut without undergoing any deformation or stretching, maintaining a constant length.

5. What characterizes an ideal pulley, based on the information provided?

   A) It has significant mass and rotates about an axle with high friction.
   B) It has negligible mass and does not rotate about an axle.
   C) It has significant mass and rotates about an axle without friction.
   D) It has negligible mass and rotates about an axle with negligible friction.

Answer: D) It has negligible mass and rotates about an axle with negligible friction

Explanation: An ideal pulley is defined as having negligible mass and rotating about an axle with negligible friction. This description implies that an ideal pulley does not add significant mass to the system and does not introduce any additional resistance or friction to the system, allowing for smooth, frictionless rotation about its axle.

Free Response Questions

1. Explain Newton's third law of motion and provide an example to illustrate how it relates to the interaction between two objects.
2. Draw a diagram representing the interaction between a person pushing a wall and the wall exerting a reaction force on the person. Label the forces and explain how they demonstrate Newton's third law.
3. In what ways does Newton's third law contribute to the understanding of action-reaction forces? Explain with reference to a specific real-life scenario.
4. Choose a practical example from sports or everyday life where Newton's third law is prominently at play. Describe the forces involved and explain how they demonstrate the law of action and reaction.
5. Elaborate on the importance of considering Newton's third law in engineering and design. Provide an example where neglecting the implications of this law could lead to design flaws or safety hazards.

Answers:

1. Newton's third law of motion states that for every action, there is an equal and opposite reaction. For instance, when a person pushes against a wall, the wall exerts an equal force back on the person, preventing the person from moving through the wall.
2. The diagram should depict a person pushing against a wall. The forces involved are:
   - The force exerted by the person on the wall (action force)
   - The reaction force exerted by the wall on the person (equal and opposite to the action force)
   - This representation demonstrates Newton's third law as the two forces are equal in magnitude and opposite in direction.
3. Newton's third law helps us understand that when one object exerts a force on another, the second object exerts an equal force in the opposite direction. An example could be the propulsion of a rocket where the expulsion of gas downward propels the rocket upwards.
4. Example scenario: A person rowing a boat. Forces involved:
   - Person pushing the water with the oar (action force)
   - Water pushing the boat forward (reaction force)

- This demonstrates Newton's third law, where the action of rowing exerts a force on the water, and the reaction of the water exerts an equal and opposite force propelling the boat forward.
- Considering Newton's third law is crucial in engineering and design, particularly in ensuring structural integrity and safety. Neglecting this law could lead to design flaws, such as overlooking the potential impact of reactive forces on structures. For instance, in the design of tall buildings, engineers must consider the equal and opposite forces exerted on the foundation to prevent structural failure or instability.

Learning Objective	**Essential Knowledge**
2.4.A Describe the conditions under which a system's velocity remains constant. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	2.4.A.1 The net force on a system is the vector sum of all forces exerted on the system. 2.4.A.2 Translational equilibrium is a configuration of forces such that the net force exerted on a system is zero. 2.4.A.3 Newton's first law states that if the net force exerted on a system is zero, the velocity of that system will remain constant. 2.4.A.4 Forces may be balanced in one dimension but unbalanced in another. The system's velocity will change only in the direction of the unbalanced force. 2.4.A.5 An inertial reference frame is one from which an observer would verify Newton's first law of motion. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)

1. According to the provided information, what is the net force on a system?

   A) The sum of all forces acting on the system.

   B) The difference between the largest and smallest forces.

   C) The average of all forces acting on the system.

   D) The product of all forces acting on the system.

Answer: A) The sum of all forces acting on the system

Explanation: The net force on a system is defined as the vector sum of all forces acting on the system. This implies that all forces acting on the system are combined using vector addition to determine the overall net force.

2. What does translational equilibrium of a system imply?

   A) The system is at rest.

   B) The system is in constant motion.

   C) The net force exerted on the system is zero.

   D) The system is undergoing acceleration.

Answer: C) The net force exerted on the system is zero

Explanation: Translational equilibrium of a system implies that the net force exerted on the system is zero. This condition suggests that all forces acting on the system are balanced, resulting in a state where there is no overall acceleration or change in the system's velocity.

3. According to Newton's first law, what happens to the velocity of a system if the net force exerted on it is zero?

   A) The velocity increases.
   B) The velocity decreases.
   C) The velocity remains constant.
   D) The velocity fluctuates randomly.

Answer: C) The velocity remains constant

Explanation: According to Newton's first law, if the net force exerted on a system is zero, the system's velocity will remain constant. This principle highlights the concept of inertia, where an object at rest stays at rest and an object in motion continues to move at a constant velocity unless acted upon by an external force.

4. In what circumstances will a system's velocity change in one dimension?

   A) When the net force is zero.
   B) When the forces are balanced in all dimensions.
   C) When the forces are balanced in one dimension but unbalanced in another.

D) When the forces are unbalanced in all dimensions.

Answer: C) When the forces are balanced in one dimension but unbalanced in another

Explanation: Forces may be balanced in one dimension but unbalanced in another. In this case, the system's velocity will change only in the direction of the unbalanced force. This emphasizes the idea that forces acting on a system can influence its motion in specific dimensions while not affecting other dimensions.

5. What characterizes an inertial reference frame, based on the provided information?

   A) A frame of reference with constant velocity.
   B) A frame of reference at rest.
   C) A frame of reference in uniform circular motion.
   D) A frame of reference verifying Newton's first law of motion.

Answer: D) A frame of reference verifying Newton's first law of motion

Explanation: An inertial reference frame is characterized as a frame of reference from which an observer would verify Newton's first law of motion. This concept suggests that in an inertial reference frame, a system remains at a constant velocity or at rest unless acted upon by an external force, aligning with the principles of inertia and the absence of net external forces.

Free Response Questions

1. Define constant velocity in the context of motion. Provide an example of a real-life scenario that demonstrates constant velocity.
2. Explain the concept of inertia and how it relates to an object's tendency to maintain constant velocity. Provide an example to illustrate your explanation.
3. Describe the key factors that contribute to a system's velocity remaining constant. Provide examples to support your explanation.
4. Discuss the role of balanced forces in maintaining the constant velocity of an object. Use a specific scenario to illustrate how balanced forces impact the object's motion.
5. Elaborate on the significance of understanding the conditions for constant velocity in the context of transportation and safety. Provide an example where adherence to these principles is critical for ensuring safe and efficient transportation systems.

Answers:

1. Constant velocity refers to the situation when an object maintains a steady speed in a straight line. An example could be a car moving at a consistent speed on a highway without changing its direction.

2. Inertia is the tendency of an object to resist changes in its state of motion. Objects with greater mass exhibit greater inertia, making it more difficult to change their velocity. For instance, a heavy book placed on a table will remain at rest until an external force is applied.
3. Factors contributing to a system's velocity remaining constant include the absence of unbalanced external forces, a frictionless environment, and no change in the direction of motion. For example, a satellite orbiting the Earth at a constant speed in a vacuum demonstrates these conditions.
4. Balanced forces play a crucial role in maintaining constant velocity. In a scenario where a car is moving at a steady speed on a straight road, the driving force from the engine is balanced by the opposing frictional force and air resistance. This balance ensures that the car's velocity remains constant.
5. Understanding the conditions for constant velocity is vital in transportation to ensure the safety and efficiency of systems. For instance, in aviation, maintaining a constant velocity during flight is crucial for stable and safe travel. Any sudden changes in speed or direction could lead to turbulence or even accidents, emphasizing the importance of adhering to the principles of constant velocity.

Learning Objective	**Essential Knowledge**
2.5.A Describe the conditions under which a system's velocity changes. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	2.5.A.1 Unbalanced forces are a configuration of forces such that the net force exerted on a system is not equal to zero. 2.5.A.2 Newton's second law of motion states that the acceleration of a system's center of mass has a magnitude proportional to the magnitude of the net force exerted on the system and is in the same direction as that net force. Relevant equation: $$a_{sys} = \frac{\Sigma \mathrm{F}}{m_{sys}} = \frac{F_{net}}{m_{sys}}$$ 2.5.A.3 The velocity of a system's center of mass will only change if a non-zero net external force is exerted on that system. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)

1. What characterizes unbalanced forces?

    A) They are forces that are equal in magnitude but opposite in direction.

    B) They are forces that cancel each other out.

    C) They are forces that result in a zero net force.

    D) They are forces that result in a non-zero net force.

Answer: D) They are forces that result in a non-zero net force

Explanation: Unbalanced forces are characterized as forces that result in a non-zero net force. This implies that the forces acting on a system do not cancel each other out, resulting in a net force that is not equal to zero. Consequently, this non-zero net force leads to changes in the system's motion or acceleration.

2. According to Newton's second law of motion, what is the relationship between the acceleration of a system's center of mass and the net force exerted on the system?

    A) They are inversely proportional.

    B) They are unrelated.

    C) They have a direct proportional relationship.

    D) They have a complex relationship.

Answer: C) They have a direct proportional relationship

Explanation: According to Newton's second law of motion, the acceleration of a system's center of mass has a direct proportional relationship with the net force exerted on the system. This relationship is mathematically defined by the equation:

$$a_{sys} = \frac{\Sigma \mathrm{F}}{m_{sys}} = \frac{F_{net}}{m_{sys}}$$

This indicates that the acceleration is directly proportional to the net force and inversely proportional to the mass of the system.

3. When will the velocity of a system's center of mass change?

   A) When there is a balanced net external force.
   B) When there is no external force exerted on the system.
   C) When a non-zero net external force is exerted on the system.
   D) When any combination of forces is applied to the system.

Answer: C) When a non-zero net external force is exerted on the system

Explanation: The velocity of a system's center of mass will change when a non-zero net external force is exerted on the system. This condition highlights the significance of external forces in altering the motion of a system, emphasizing that changes in velocity or acceleration occur only when an unbalanced net external force acts on the system.

Free Response Questions

1. Define the concept of velocity change in the context of motion. Provide an example of a real-life scenario that demonstrates a change in velocity.
2. Explain the role of external forces in altering an object's velocity. Provide an example to illustrate how external forces can change an object's velocity.
3. Describe the influence of friction on an object's velocity. Explain how friction affects the motion of an object, leading to a change in its velocity. Provide examples to support your explanation.
4. Discuss the impact of unbalanced forces on altering the velocity of a system. Use a specific scenario to illustrate how unbalanced forces can lead to a change in the system's velocity.
5. Elaborate on the significance of understanding the conditions for changing velocity in the context of sports and safety. Provide an example where the comprehension of these principles is essential for optimizing performance and ensuring safety in sports activities.

Answers:

1. A change in velocity refers to the alteration in the speed or direction of an object's motion. An example of this could be a car accelerating from rest to a certain speed, or a

ball thrown upwards experiencing a change in its upward velocity before it starts falling back down.

2. External forces play a significant role in changing an object's velocity. For instance, when a person kicks a football, the force exerted by the kick alters the ball's initial velocity, leading to a change in its speed and possibly direction.
3. Friction has a notable impact on an object's velocity. It acts opposite to the direction of the object's motion, slowing it down and leading to a change in its velocity. An example could be a moving car gradually slowing down due to the friction between its tires and the road surface.
4. Unbalanced forces can cause a system's velocity to change. For example, when a rocket launches, the thrust from the engines creates an unbalanced force, accelerating the rocket upward and causing a change in its velocity.
5. Understanding the conditions for changing velocity is crucial in sports for optimizing performance and ensuring safety. In a sport like baseball, comprehending how different forces like bat swing and air resistance impact the ball's velocity helps players make strategic decisions and ensures the safety of players and spectators during the game.

Learning Objective	**Essential Knowledge**
2.6.A Describe the gravitational interaction between two objects or systems with mass. 2.6.B Describe situations in which the gravitational force can be considered constant. 2.6.C Describe the conditions under which the magnitude of a system's apparent weight is different from the magnitude of the gravitational force exerted on that system. 2.6.D Describe inertial and gravitational mass. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	2.6.A.1 Newton's law of universal gravitation describes the gravitational force between two objects or systems as directly proportional to each of their masses and inversely proportional to the square of the distance between the systems' centers of mass. Relevant equation: $$F_g = G\,\frac{m_1 m_2}{r^2}$$ i. The gravitational force is attractive. ii. ii. The gravitational force is always exerted along the line connecting the centers of mass of the two interacting systems. iii. iii. The gravitational force on a system can be considered to be exerted on the system's center of mass. 2.6.A.2 A field model the effects of non contact force exerted on an object at various positions in space. i. The magnitude of the gravitational field created by a system of mass M at a point in space is equal to the ratio of the gravitational force exerted by the system on a test object of mass m to the mass of the test object.

	ii. If the gravitational force is the only force exerted on an object, the observed acceleration of the object (in m/s2) is numerically equal to the magnitude of the gravitational field strength (in N/Kg) at that location. 2.6.A.3 The gravitational force exerted by an astronomical body on a relatively small nearby object is called weight. Derived Equation: Weight = F_g = mg 2.6.B.1 If the gravitational force between two systems' centers of mass has a negligible change as the relative position of the two systems changes, the gravitational force can be considered constant at all points between the initial and final positions of the systems. 2.6.B.2 Near the surface of Earth, the strength of the gravitational field is g = 10 N/kg 2.6.C.1 The magnitude of the apparent weight of a system is the magnitude of the normal force exerted on the system.

	2.6.C.2 If the system is accelerating, the apparent weight of the system is not equal to the magnitude of the gravitational force exerted on the system. 2.6.C.3 A system appears weightless when there are no forces exerted on the system or when the force of gravity is the only force exerted on the system. 2.6.C.4 The equivalence principle states that an observer in a non inertial reference frame is unable to distinguish between an object's apparent weight and the gravitational force exerted on the object by a gravitational field. 2.6.D.1 Objects have inertial mass, or inertia, a property that determines how much an object's motion resists changes when interacting with another object. 2.6.D.2 Gravitational mass is related to the force of attraction between two systems with mass. 2.6.D.3 Inertial mass and gravitational mass have been experimentally verified to be equivalent. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)

1. What does the field model in physics describe?

   A) The interactions between charged particles.

   B) The effects of non-contact forces on objects in space.

   C) The behavior of objects in a vacuum.

   D) The interactions between particles at the quantum level.

Answer: B) The effects of non-contact forces on objects in space

Explanation: The field model in physics describes the effects of non-contact forces on objects in space. It encompasses the gravitational field and other fields, allowing for the understanding of the influence of these forces on objects or systems at various positions in space. It helps model the interaction between objects without direct contact.

2. What does the equivalence principle state in relation to an object's apparent weight and the gravitational force?

   A) They are always equal in value.

   B) They are different inertial reference frames.

C) They are equal only in a non-inertial reference frame.

D) They are indistinguishable in a non-inertial reference frame.

Answer: D) They are indistinguishable in a non-inertial reference frame

Explanation: The equivalence principle states that an observer in a non-inertial reference frame is unable to distinguish between an object's apparent weight and the gravitational force exerted on the object by a gravitational field. This principle emphasizes the equivalence of the effects of gravitational force and apparent weight in the context of a non-inertial reference frame, highlighting the difficulty in discerning between the two.

3. What property of an object determines its resistance to changes in motion when interacting with another object?

   A) Gravitational mass

   B) Inertial mass

   C) Velocity

   D) Density

Answer: b) Inertial mass

Explanation: Inertial mass is the property of an object that determines its resistance to changes in motion when interacting with another object. It represents the measure of the object's resistance to acceleration and is a fundamental characteristic that defines how the object responds to external forces.

4. According to the given information, what is weight in the context of gravitational force?

    A) The force of gravity acting on an object.

    B) The mass of an object.

    C) The force of inertia acting on an object.

    D) The force of friction acting on an object.

Answer: A) The force of gravity acting on an object

Explanation: Weight, in the context of gravitational force, refers to the force of gravity acting on an object. It represents the gravitational force exerted on an object due to the mass of the object and the gravitational field strength. Weight is the measure of the gravitational force experienced by an object due to the influence of gravity.

Free Response Questions

1. Explain the concept of gravitational interaction between two objects or systems with mass. Provide an example to illustrate how the gravitational force operates between the objects or systems.

2. Describe a scenario in which the gravitational force can be considered constant. Explain the factors that contribute to the constancy of the gravitational force in this situation.
3. Define the term "apparent weight" in the context of gravitational force. Provide an example where the apparent weight of an object differs from the actual gravitational force acting on it.
4. Elaborate on the factors that can cause the magnitude of a system's apparent weight to differ from the magnitude of the gravitational force exerted on that system. Use specific examples to support your explanation.
5. Discuss the concept of weightlessness in the context of gravitational interactions. Provide an example of a situation where apparent weightlessness occurs and explain the underlying reasons for this phenomenon.
6. Describe the gravitational force between the Earth and the Moon. Explain how this interaction affects the motion of the Moon and tides on the Earth.
7. Explain the concept of free fall in the context of gravitational interactions. Provide an example to illustrate the effects of free fall and how it relates to the gravitational force acting on the falling object.
8. Discuss the impact of distance on the gravitational force between two objects. Describe how the distance between objects affects the strength of the gravitational force and provide real-life examples to support your explanation.

9. Describe a scenario where the gravitational force is not the only force acting on an object or system. Explain how the presence of other forces influences the overall motion of the object or system in this scenario.
10. Elaborate on the significance of understanding gravitational interactions in the context of space exploration. Provide an example of how knowledge of gravitational forces influences spacecraft trajectories and missions in space.

Answers:

1. Gravitational interaction is the force of attraction between two objects with mass. For example, the gravitational force between the Earth and a satellite keeps the satellite in orbit around the Earth.
2. In a scenario where the distance between two objects remains constant, the gravitational force between them can be considered constant. Factors such as the masses of the objects and the universal gravitational constant contribute to the constancy of the gravitational force.
3. Apparent weight refers to the measure of the force exerted by a supporting surface on an object. An example is the apparent weight of an elevator passenger changing as the elevator accelerates upward or downward.

4. The magnitude of a system's apparent weight can differ from the magnitude of the gravitational force due to additional forces like normal force or acceleration. For example, a person in an elevator experiences a change in apparent weight due to the presence of acceleration forces during the elevator's movement.
5. Weightlessness occurs when an object or person experiences a sensation of no apparent weight due to the absence of a support force countering the gravitational force. An example is astronauts in a state of apparent weightlessness in space due to the continuous free fall experienced in orbit.
6. The gravitational force between the Earth and the Moon governs the Moon's orbit around the Earth and creates tidal effects on the Earth due to the Moon's gravitational pull on the Earth's oceans.
7. Free fall refers to the motion of an object under the sole influence of gravitational force. An example is a skydiver falling toward the ground, experiencing a continuous increase in speed due to the gravitational pull.
8. The strength of the gravitational force between two objects is inversely proportional to the square of the distance between their centers. For instance, the gravitational force between the Sun and planets decreases as the distance from the Sun increases.
9. In scenarios where the gravitational force is not the only force acting, the presence of other forces such as friction, air resistance, or applied forces influences the overall motion of the object or system. For example, a ball thrown upwards experiences the gravitational force and air resistance simultaneously.

10. Understanding gravitational interactions is crucial in space exploration as it enables precise trajectory calculations and mission planning. For instance, the knowledge of gravitational forces between celestial bodies helps spacecraft navigate accurately and conserve fuel during long space missions.

Learning Objective	**Essential Knowledge**
2.7.A Describe kinetic friction between two surfaces. 2.7.B Describe static friction between two surfaces. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	2.7.A.1 Kinetic friction occurs when two surfaces in contact move relative to each other. i. The kinetic friction force is exerted in a direction opposite to the motion of each surface relative to the other surface. ii. The force of friction between two surfaces does not depend on the size of the surface area of contact. 2.7.A.2 The magnitude of the kinetic friction force exerted on an object is the product of the normal force the surface exerts on the object and the coefficient of kinetic friction. Relevant equation: $$F_{fk} = \mu_k F_N$$ i. The coefficient of kinetic friction depends on the material properties of the surfaces that are in contact. ii. Normal force is the perpendicular component of the force exerted on an object by the surface with which it is in contact; it is directed away from the surface.

	2.7.B.1 Static friction may occur between the contacting surfaces of two objects that are not moving relative to each other. 2.7.B.2 Static friction adopts the value and direction required to prevent an object from slipping or sliding on a surface. Relevant equation: $F_{fs,max} \leq \mu_s F_N$ i. Slipping and sliding refer to situations in which two surfaces are moving relative to each other. ii. There exists a maximum value for which static friction will prevent an object from slipping on a given surface. Derived equation: $F_{fs,max} = \mu_s F_N$ 2.7.B.3 The coefficient of static friction is typical greater than the coefficient of kinetic friction for a given pair of surfaces. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)

1. When does kinetic friction occur between two surfaces?

   A) When the surfaces are at rest relative to each other.

   B) When the surfaces are accelerating.

   C) When the surfaces are in contact and moving relative to each other.

   D) When the surfaces are stationary.

Answer: C) When the surfaces are in contact and moving relative to each other

Explanation: Kinetic friction occurs between two surfaces when they are in contact and moving relative to each other. This type of friction force acts in a direction opposite to the motion of the surfaces. It represents the resistance encountered by moving surfaces and is a result of the interaction between the surfaces.

2. What does the coefficient of kinetic friction depend on, according to the provided information?

   A) The velocity of the moving surfaces.

   B) The surface area of the objects in contact.

   C) The material properties of the surfaces in contact.

   D) The temperature of the surfaces in contact.

Answer: C) The material properties of the surfaces in contact

Explanation: The coefficient of kinetic friction depends on the material properties of the surfaces in contact. This coefficient is a measure of the frictional force between two surfaces when they are in motion relative to each other. It represents the specific interaction between the materials and is essential for understanding the resistance encountered during relative motion.

3. Under what circumstances does static friction occur between two surfaces?

   A) When the surfaces are at rest relative to each other.
   B) When the surfaces are in contact and moving relative to each other.
   C) When the surfaces are stationary.
   D) When the surfaces are sliding past each other.

Answer: A) When the surfaces are at rest relative to each other

Explanation: Static friction occurs between two surfaces when they are at rest relative to each other. It prevents the objects from sliding or slipping and adopts a value and direction required to maintain the stationary state of the objects. Static friction is the force that counteracts the tendency of the surfaces to slide over each other.

4. What characterizes the coefficient of static friction compared to the coefficient of kinetic friction for a given pair of surfaces?

   A) It is typically equal to the coefficient of kinetic friction.
   B) It is typically less than the coefficient of kinetic friction.
   C) It is typically greater than the coefficient of kinetic friction.
   D) It is independent of the surfaces in contact

Answer: c) It is typically greater than the coefficient of kinetic friction

Explanation: The coefficient of static friction is typically greater than the coefficient of kinetic friction for a given pair of surfaces. This difference arises due to the variations in the interaction between surfaces in static and kinetic states. The coefficient of static friction plays a critical role in preventing the initial movement or slipping of surfaces in contact.

5. What does the maximum value of static friction prevent in relation to the object and the surface?

   A) Slipping
   B) Acceleration
   C) Friction
   D) Vibration

Answer: a) Slipping

Explanation: The maximum value of static friction prevents slipping between the object and the surface. This maximum static friction force acts in the opposite direction of the impending motion and is responsible for maintaining the stability and stationary state of the surfaces. It acts as a limiting force that prevents the objects from sliding or slipping.

Free Response Questions

1. Explain the concept of kinetic friction between two surfaces. Provide an example of a real-life scenario that demonstrates kinetic friction and its effects on the motion of objects.
2. Describe the factors that influence the magnitude of kinetic friction between two surfaces. Provide examples to illustrate how these factors affect the strength of the kinetic frictional force.
3. Define static friction between two surfaces. Elaborate on the conditions under which static friction comes into play and prevents the relative motion between the surfaces.
4. Compare and contrast kinetic friction and static friction in terms of the factors affecting their strengths and the conditions under which they operate. Provide examples to support your comparison.
5. Discuss the role of surface properties in determining the magnitude of frictional forces. Explain how variations in surface textures and materials influence the frictional forces between surfaces.

6. Explain the implications of friction in the context of everyday activities such as walking or driving. Provide examples to demonstrate how an understanding of friction is essential for ensuring safety and efficiency in these activities.
7. Discuss the significance of minimizing friction in mechanical systems. Provide an example where reducing friction is critical for enhancing the performance and longevity of the mechanical components.
8. Describe the impact of lubricants in reducing friction between surfaces. Explain how the application of lubricants alters the frictional forces and enhances the efficiency of the interacting surfaces.

Answers:

1. Kinetic friction is the resistance between moving surfaces. An example is the friction between the tires of a car and the road, which influences the car's ability to accelerate or decelerate.
2. Factors influencing the magnitude of kinetic friction include the nature of the surfaces, the presence of any lubricants, and the normal force pressing the surfaces together. For example, rough surfaces tend to have higher kinetic friction than smoother ones.
3. Static friction is the force that prevents the relative motion between two surfaces at rest. It comes into play when an applied force is not sufficient to overcome the frictional force keeping the surfaces stationary.

4. Kinetic friction occurs between moving surfaces, while static friction operates between stationary surfaces. While both depend on the nature of the surfaces and the normal force, kinetic friction involves relative motion, whereas static friction prevents such motion. An example is pushing a heavy box on the floor (static friction) versus sliding the box (kinetic friction).
5. Surface properties such as roughness, texture, and material composition significantly impact the magnitude of frictional forces. Surfaces with rough textures or high coefficients of friction tend to exhibit stronger frictional forces.
6. Understanding friction is crucial for ensuring safety and efficiency in everyday activities such as walking or driving. For instance, knowing the friction between shoes and the ground helps prevent slipping while walking, and understanding tire-road friction is essential for maintaining control while driving.
7. Minimizing friction in mechanical systems is vital for enhancing performance and longevity. For example, reducing friction in the moving parts of engines or machinery helps improve efficiency, decrease wear and tear, and conserve energy.
8. Lubricants reduce friction between surfaces by creating a thin layer that separates the surfaces and minimizes direct contact. This application significantly decreases the frictional forces, thereby reducing wear and heat generation, and improving the overall efficiency of the interacting surfaces.

Learning Objective	**Essential Knowledge**
2.8.A Describe the force exerted on an object by an ideal spring (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	2.8.A.1 An ideal spring has negligible mass and exerts a force that is proportional to the change in its length as measured from its relaxed length. 2.8.A.2 The magnitude of the force exerted by an ideal spring on an object is given by Hooke's law: =−Δ Fkx s $$F_s = -k\Delta x$$ 2.8.A.3 The force exerted on an object by a spring is always directed toward the equilibrium position of the object–spring system. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)
1. What type of force does an ideal spring exert that is proportional to the change in its length from its relaxed state? A) Gravitational force B) Tension force C) Frictional force D) Restoring force

Answer: D) Restoring force

Explanation: An ideal spring exerts a restoring force that is proportional to the change in its length from its relaxed state. This force is responsible for pulling the spring back to its equilibrium position when stretched or compressed. It acts in a direction that tends to restore the spring to its original state, hence the name "restoring force."

2. Which law describes the magnitude of the force exerted by an ideal spring on an object?

    A) Kepler's law
    B) Ohm's law
    C) Boyle's law
    D) Hooke's law

Answer: D) Hooke's law

Explanation: Hooke's law describes the magnitude of the force exerted by an ideal spring on an object. This law mathematically expresses the linear relationship between the force exerted by the spring and the displacement of the object from its equilibrium position. It provides a fundamental understanding of how the spring force varies with the extension or compression of the spring.

3. In what direction is the force exerted by a spring on an object always directed, based on the given information?

   A) Away from the equilibrium position.

   B) Perpendicular to the equilibrium position.

   C) Toward the equilibrium position.

   D) In the direction of the displacement.

Answer: C) Toward the equilibrium position

Explanation: The force exerted by a spring on an object is always directed toward the equilibrium position of the object-spring system. This characteristic is a result of the spring's tendency to restore its original state and maintain its equilibrium position. The restoring force pulls the object back towards the equilibrium position when it is displaced from that point.

4. What is the relationship between the force exerted by the spring and the displacement of the object from its equilibrium position?

   A) They are directly proportional.

   B) They are inversely proportional.

   C) They are exponentially proportional.

   D) They vary exponentially inverse proportional.

Answer: A) They are directly proportional

Explanation: The force exerted by the spring and the displacement of the object from its equilibrium position are directly proportional to each other. This relationship is governed by Hooke's law, which states that the force exerted by the spring is directly proportional to the displacement of the spring from its equilibrium or rest position.

5. If an ideal spring is stretched or compressed beyond its elastic limit, what may happen to its behavior?

    A) The spring will exert an exponentially increasing force.

    B) The spring will return to its original state.

    C) The spring will exert a constant force.

    D) The spring may not return to its original length.

Answer: D) The spring may not return to its original length

Explanation: If an ideal spring is stretched or compressed beyond its elastic limit, it may not return to its original length. Once the elastic limit of the spring is surpassed, it undergoes permanent deformation, leading to changes in its structure that prevent it from returning to its original state. This behavior is indicative of the spring's limitations and the importance of considering the elastic properties of materials.

Free Response Questions
1. Explain the concept of an ideal spring and its behavior in relation to force. Provide an example of a real-life scenario where an ideal spring is used and explain the force exerted by the spring in that situation. 2. Define Hooke's Law and its significance in understanding the force exerted by an ideal spring. Provide an equation representing Hooke's Law and explain the meaning of each variable. 3. Describe the factors that affect the magnitude of the force exerted by an ideal spring. Elaborate on how changes in these factors influence the force exerted by the spring. 4. Explain the concept of spring constant and its role in determining the force exerted by an ideal spring. Provide an example illustrating how variations in the spring constant affect the force exerted. 5. Discuss the relationship between the displacement of the spring from its equilibrium position and the force exerted by the spring. Provide a graphical representation to demonstrate the nature of this relationship. 6. Elaborate on the application of ideal springs in engineering and design. Provide an example of a practical engineering application where the understanding of spring forces is crucial for ensuring the functionality and stability of a system.

Answers:

1. An ideal spring is a theoretical model that exhibits linear behavior in response to applied forces. An example of a real-life scenario is the use of a spring in a pogo stick, where the spring exerts a restoring force as it is compressed or stretched.
2. Hooke's Law states that the force exerted by an ideal spring is directly proportional to the displacement of the spring from its equilibrium position. The equation representing Hooke's Law is $F = -kx$, where F is the force exerted, k is the spring constant, and x is the displacement from the equilibrium position.
3. The magnitude of the force exerted by an ideal spring is influenced by factors such as the displacement from the equilibrium position, the spring constant, and the direction of the displacement. Changes in these factors affect the strength and direction of the force exerted by the spring.
4. The spring constant represents the stiffness of the spring and determines the force exerted for a given displacement. For instance, a higher spring constant indicates a stiffer spring that requires more force to produce the same displacement compared to a spring with a lower spring constant.
5. The relationship between the displacement of the spring from its equilibrium position and the force exerted is linear, as described by Hooke's Law. A graphical representation of this relationship would show a straight line passing through the origin with a slope equal to the spring constant.

6. Ideal springs find application in various engineering and design contexts, such as in the suspension systems of vehicles. Understanding spring forces is crucial in ensuring the stability and functionality of the suspension system, as the spring's response to external forces affects the ride quality and handling performance of the vehicle.

Learning Objective	**Essential Knowledge**
2.9.A Describe the motion of an object traveling in a circular path. (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)	2.9.A.1 Centripetal acceleration is the component of an object's acceleration directed toward the center of the object's circular path. i. The magnitude of centripetal acceleration for an object moving in a circular path is the ratio of the object's tangential speed squared to the radius of the circular path. Relevant equation: $$a_c = \frac{v^2}{r}$$ ii. Centripetal acceleration is directed toward the center of an object's circular path. 2.9.A.2 Centripetal acceleration can result from a single force, more than one force, or components of forces exerted on an object in circular motion. i. At the top of a vertical, circular loop, an object requires a minimum speed to maintain circular motion. At this point, and with this minimum speed, the gravitational force is the only force that causes the centripetal acceleration. Derived equation:

	$$v = \sqrt{gr}$$ ii. Components of the static friction force and the normal force can contribute to the net force producing centripetal acceleration of an object traveling in a circle on a banked surface. iii. A component of tension contributes to the net force producing centripetal acceleration experienced by a conical pendulum. 2.9.A.3 Tangential acceleration is the rate at which an object's speed changes and is directed tangent to the object's circular path. 2.9.A.4 The net acceleration of an object moving in a circle is the vector sum of the centripetal acceleration and tangential acceleration. 2.9.A.5 The revolution of an object traveling in a circular path at a constant speed (uniform circular motion) can be described using period and frequency. i. The time to complete one full circular path is defined as period, T.

	ii. The rate at which an object is completing revolutions is defined as frequency, f. Relevant equation: $$T = \frac{1}{f}$$ iii. For an object traveling at a constant speed in a circular path, the period is given by the derived equation: $$T = \frac{2\pi r}{v}$$ (*AP Physics 1 COURSE FRAMEWORK AND EXAM OVERVIEW*)

Multiple Choice Questions (Instant Feedback)

1. What is centripetal acceleration, as defined by the provided information?

   A) The component of an object's acceleration directed away from the center of its circular path.

   B) The component of an object's acceleration directed toward the center of its circular path.

   C) The component of an object's velocity directed away from the center of its circular path.

   D) The component of an object's velocity directed toward the center of its circular path.

Answer: B) The component of an object's acceleration directed toward the center of its circular path

Explanation: Centripetal acceleration, as defined by the provided information, is the component of an object's acceleration directed toward the center of its circular path. This type of acceleration is essential for an object to maintain its circular motion, as it is responsible for constantly changing the direction of the object's velocity while it moves in a circular path.

2. Which force or forces can contribute to the net force producing centripetal acceleration in an object traveling in a circle on a banked surface?

   A) Gravitational force only.

   B) Tension force only.

C) Normal force and static friction force components.

D) Normal force only.

Answer: C) Normal force and static friction force components

Explanation: Normal force and static friction force components can contribute to the net force producing centripetal acceleration in an object traveling in a circle on a banked surface. In such a scenario, these forces, along with other factors, play a crucial role in maintaining the circular motion of the object on the banked surface. Since both forces have components in the horizontal direction, they both contribute to the centripetal force.

3. What is tangential acceleration?

A) The rate at which an object's speed remains constant.

B) The rate at which an object's speed changes and is directed tangent to the object's circular path.

C) The rate at which an object's speed changes and is directed toward the center of the object's circular path.

D) The rate at which an object's speed changes and is directed away from the center of the object's circular path.

Answer: B) The rate at which an object's speed changes and is directed tangent to the object's circular path

Explanation: Tangential acceleration refers to the rate at which an object's speed changes and is directed tangent to the object's circular path. This type of acceleration signifies the change in speed of the object while it is moving along the circular path, and it points in the direction tangent to the path at any given point.

4. What does the period of an object traveling in a circular path represent?

   A) The distance covered by the object in one circular path.
   B) The time to complete one full circular path.
   C) The rate at which the object is completing revolutions.
   D) The speed of the object in the circular path

Answer: B) The time to complete one full circular path

Explanation: The period of an object traveling in a circular path represents the time it takes for the object to complete one full circular path. This period is a fundamental aspect of the object's circular motion and is crucial in understanding the time required for the object to return to its original starting point in the circular path.

Free Response Questions

1. Define circular motion and explain the key characteristics of an object moving in a circular path. Provide an example from daily life that demonstrates circular motion.
2. Describe the concept of centripetal acceleration in the context of circular motion. Explain how centripetal acceleration is related to the change in the direction of an object's velocity.
3. Elaborate on the role of centripetal force in maintaining the circular motion of an object. Provide an example that illustrates how centripetal force is responsible for keeping an object in a circular path.
4. Explain the difference between uniform circular motion and non-uniform circular motion. Provide examples of each type of circular motion to illustrate the distinction.
5. Discuss the relationship between the speed of an object in circular motion and its radius of curvature. Elaborate on how changes in speed and radius affect the centripetal acceleration experienced by the object.
6. Describe the application of circular motion principles in the design and operation of amusement park rides. Provide an example of a specific ride where an understanding of circular motion is crucial for ensuring the safety and enjoyment of the participants.

Answers:

1. Circular motion is the movement of an object along a circular path. Key characteristics include constant change in direction, a fixed distance from the center, and a continuous velocity. An example from daily life is the motion of a car around a roundabout.
2. Centripetal acceleration is the acceleration directed towards the center of the circular path, keeping the object in its circular trajectory. It is related to the change in the direction of the object's velocity, ensuring that the object continuously changes direction without deviating from the circular path.
3. Centripetal force is the force acting towards the center of the circular path that maintains the object's motion along the circular trajectory. An example is the tension in a string that keeps a ball moving in a circle when swung around on a string.
4. Uniform circular motion refers to motion at a constant speed along a circular path, while non-uniform circular motion involves variations in speed during the circular path. An example of uniform circular motion is a satellite in orbit, while a car driving along a winding road represents non-uniform circular motion.
5. The speed of an object in circular motion is directly related to its radius of curvature. An increase in speed or a decrease in the radius of curvature results in a higher centripetal acceleration experienced by the object, while a decrease in speed or an increase in the radius leads to a lower centripetal acceleration.

6. Circular motion principles are crucial in designing and operating amusement park rides, such as the Ferris wheel. Understanding circular motion ensures the safety of the participants by maintaining the ride's stability and the enjoyment of the participants by creating a thrilling experience within a controlled environment.

Appendix B: Lab Report Rubric and Guidelines

Section	Description	Full Expectations	Points Awarded	Notes or Authors
Purpose (2)	Both the intermediate and competitive goal are clearly stated.	1) Both goals are clearly stated.		
Introduction (4)	The introduction should include all background physics principles and equations used in this experiment.	1) All Physics principles needed for the lab are referenced. 2) All equations used are referenced. 3) Is clear and easy to read. 4) Any outside sources used are referenced and cited in APA format.		

Procedure (8)	Procedure needs to clearly (and simply) describe the process by which your data was obtained. This should be written at a level where a peer in AP chem/bio/environmental science could replicate your exact process and obtain similar data without any previous experience in physics.	1) A clear description of how all measurements were made is present. Paragraphs, bullet points, or numbered steps are all allowable. 2) Every tool used to make a measurement should be named. 3) The units used to make each measurement should be included. 4) Steps to mitigate random error should be included. (REPEAT TRIALS) 5) Steps to mitigate systematic error should be included (Multiple data points, minimize invalid assumptions). 6) Diagram(s) for set up is/are included.		

		7) Language is clear, easy to read, in past tense, and in the 3rd person. 8) NO CALCULATIONS ARE REFERENCED.		
Data (4)	A scientific data table which includes all measurements obtained in the procedure.	1) All measurements made are present. 2) Units are made clear in either the title of column or in each measurement. 3) Averages are included in an appropriate scenario. 4) Data is clear and easily decipherable. * Calculated values can be included, but they should be noted to be calculated. -1		

		point for not noting a value is calculated. * *Graphs are NOT in this section. Graphs will be docked -1 point. *		
Analysis (5)	Analysis of data should be in this section. All calculations and graphs should be here. Work may be done by hand but should be screen shotted in.	1) All algebraic derivations are to be shown here. 2) Substitutions and calculations are to be shown for ONE TRIAL ONLY per calculation. 3) All required graphs are present. 4) All calculations used for competitive goal are clearly stated. 5) Section is organized and coherent.		

Error (Systematic and Random) (5)	Based on your measuring tools and procedure, discuss the flaws in your experiment and what could be done to fix both.	1) Discuss the random error caused by the measuring tool and practices. 2) Discuss the precision you can calculate based on your least precise measurements. 3) Discuss systematic errors in your procedure, assumptions, or calculations. 4) Address how you would change your procedure and assumptions in a follow up experiment. 5) Written coherently and succinctly		
Questions (Lab Specific)	Answer any lab specific questions provided.	Each question per lab will be worth 2 points. 1 point will be made for answering the question accurately. 1 point		

		will be awarded for elaborating and tying in evidence and/or reasoning supporting the claim made.		
Conclusion (3)	The conclusion addresses the purposes of the lab and whether the experiment was successful or unsuccessful in terms of the provided goals.	"1) The goal is stated to be successful or unsuccessful. 2) Evidence is provided relevant to the claim about the success of the goal. 3) There is reasoning tying the evidence to the goal in a logical manner."		

General Comments and Feedback			Total Points:	

Appendix C: Peer Grading Expectations and Accountability Rubric

Assignment Expectations: When peer grading, you should reference every point on the lab rubric in either a positive confirmation or constructive feedback on how the author could obtain that point. When specifically instructed, the grader may only give feedback on certain sections of the lab.

Section	Points Critiqued	Total Points
Purpose	___1	/1
Introduction	___1 ___2 ___ 3 ___4	/4
Procedure	___1 ___2 ___ 3 ___4 ___5 ___6 ___ 7 ___8	/8
Data	___1 ___2 ___ 3 ___4	/4
Analysis	___1 ___2 ___ 3 ___4 ___5	/5
Error	___1 ___2 ___ 3 ___4 ___5	/5
Questions		
Conclusion	___1 ___2 ___ 3	/3

Total	[redacted]	

Accuracy Accountability: Grader total scores are expected to match the instructor's scores, within 5%.

Instructor's Score	Grader's Score	Difference

Difference	Score (out of 10 points)	Notes
≥5%	10	
5%-10%	9	
11%-20%	8	
21%-30%	7	
31%-40%	6	
41-100%	5	

Total Scores

Points for Critique	Accuracy Accountability	Total

Appendix D: Laboratory Experiment Objectives and Lab Specific Questions

<table>
<tr><td colspan="2">Lab #0: 9 Graphs Lab</td></tr>
<tr><td>Lab Objectives</td><td>Lab Specific Questions</td></tr>
<tr><td>Intermediate goal: Students are to make nine graphs:

- Position, velocity, acceleration of constant velocity cart.

- Position, velocity, acceleration of constant acceleration fan cart.

- Position, velocity, acceleration of object in free fall (ball being dropped).

Contest goal: Predict the spot where constant velocity cart and constant acceleration cart will collide when started simultaneously on opposite sides of 15 m course.</td><td>1) What features do you notice that are different between graphs of constant velocity objects and uniform acceleration objects?
2) What information can you obtain from position vs time graphs?
3) What information can you obtain from velocity v time graphs?</td></tr>
</table>

Lab #1: 1D kinematics	
Lab Objectives	Lab Specific Questions
Intermediate goal: Determine the acceleration of a block slid on the floor. Contest Goal: predict where the block will stop when slid with a given initial velocity.	1) What tools would be beneficial in acquiring better data for this lab? 2) What unforeseen variables may have made this determined acceleration be incorrect?

Lab # 2: Projectiles	
Lab Objectives	Lab Specific Questions
Intermediate Goal: Determine the velocity the ball comes out of a launcher. Competition Goal: Predict where the ball will land when it is shot off of a desk at a given angle.	1) How would the muzzle velocity you calculated have been altered if the angle in the intermediate goal had bee slightly above the horizontal? Justify your response. 2) How have you used your real-world experiences with projectiles to your advantage (think sports, games)? What are the situations you have come across that indicate your prior knowledge of projectiles?

Lab # 3: Forces (Inclined Plane)	
Lab Objectives	Lab Specific Questions
Intermediate goal: determine the angle between the surface of your inclined plane and the surface of the table using a pulley/cart system. Competition Goal: determine the mass on an unknown object without the use of a balance.	1) What would it mean if when you hooked up your mass to the pulley-cart system if the system remained at rest when released? Justify your answer. 2) Why is it possible for the system to accelerate towards a lighter weight on the pulley, instead of towards the heavier cart on the incline?

Lab #4: Conservation of Energy	
Lab Objectives	Lab Specific Questions
Intermediate Goal: Find the spring constant (k) for your spring. Competition Goal: Drop a mass attached to a string attached to your spring from a known height so that when the string is fully expanded the mass gets as close to its target height as possible. (You need to pick the length of the string. Bottom of mass should be as close to the target height as possible when spring is fully expanded).	1) Imagine this lab being done off of a high ledge. In one scenario, the student threw the pig straight up at 5 m/s and in another the student through the pig straight down at 5 m/s. Discuss both of these scenarios relative to dropping the big without throwing in terms of how far the spring would stretch.

Lab #5: Work and Energy	
Lab Objectives	Lab Specific Questions
Intermediate goal: Determine the coefficient of friction between a mass and the lab table. Contest Goal: Predict where sliding mass will stop when released as a modified Atwood double mass system.	1) How would the lab be different if the block had to slide slightly uphill? 2) Describe how the contest goal would be different if in the time frame after the mass from the Atwood machine had hit the ground but before the mass had stopped sliding, the block had hit a perfect spring. Discuss the energy transformations and what would happen to the block.

Lab #6: Collisions	
Lab Objectives	Lab Specific Questions
Goal 1: Determine if momentum and kinetic energy are conserved in collisions (elastic/inelastic) and explosions. Goal 2: Using vernier carts with different masses have some sort of collision/explosion	1) Why is momentum conserved in a collision but energy is not? 2) When an object collides with a fixed object, why is momentum not conserved? (Think molecular/atomic level).

occur then have the 2 carts hit the opposite end of the track simultaneously.	3) Where do you think energy goes when it is lost?

Lab #7: Simple Harmonic Motion	
Lab Objectives	Lab Specific Questions
Intermediate Goal: Build two oscillators; one pendulum and one spring. Determine an appropriate length of the pendulum and spring constant. Competitive Goal: Use your oscillator to blind start/stop a stopwatch as close to 1 minute as possible. ** This is essentially two labs in one. One for pendulum oscillators and one for spring oscillators. ** Rules: NO TIMING DEVICES (includes watches, phones, and computers. Watches must be left at front of room.)	1) The spring stops oscillating, where does the energy in the spring go? 2) Where does the pendulum move the fastest? The slowest?

Lab # 8: Rotational Motion and Torque	
Lab Objectives	Lab Specific Questions
Intermediate Goal: Determine the individual torques on a rotating object. Competition Goal: Determine the mass of an unknown object (meterstick) without using a balance.	1) How could you use principles in this lab to lift/move an object that is far too heavy to lift/push with your hands? 2) If you wanted to create a catapult that could throw a pumpkin as far as possible, how would you manipulate the set up to throw the pumpkin as far as possible. (You may tie in topics from other units into this response).

Lab #9: Rotational Dynamics, Moment of inertia	
Lab Objectives	Lab Specific Questions
Intermediate goal: Determine the rotational inertia of the rotating rod. Contest Goal: Determine hanging mass needed to get the same mass to fall to ground in a specified amount of time.	1) Use principles from this lab to explain how figure skaters and divers control their rotations.