AC 2010-296: PHYSICS AND MATHEMATICS LEARNING OUTCOMES OF UNDERSERVED AND UNDERREPRESENTED DREAM MENTEES AT THREE URBAN HIGH SCHOOLS

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Abstract

The DREAM Program (Designing with Rice Engineers – Achievement through Mentorship) was created in 2007 to encourage underrepresented and underprivileged high school students (mentees) toward a college education with an emphasis in STEM fields. This goal is achieved through a design project, which allows Rice University engineering students (mentors) to develop relationships with their mentees and promote higher education. Currently, DREAM serves three Houston, Texas public schools: Austin High School (AHS), Chavez High School (CHS), and KIPP Houston High School (KIPP). Mentees included in this study range from grades 9-12 at AHS, grades 9 and 11 at CHS, and only grade 9 at KIPP. Throughout the program, greater than 95% of mentees have been from underrepresented groups. Projects are designed, fabricated, and tested over a 5-7 week period. Mentees present and test their final designs at Rice University on DREAM Day.

Intuition Inventory (I.I.) and Physics Concepts Inventory (P.C.I.) data tracks the mentees progress in learning physics. The long-term goal of DREAM is to instill a passion for STEM fields in mentees. Of equal importance, mentees must be prepared for the coursework that they will face upon entering college in a STEM field. Thus, by tracking improved knowledge in physics concepts, DREAM is able to ensure that the mentees are both interested and prepared for study in STEM fields. The fact that DREAM is able to present basic physics concepts in an interactive, hands-on way allows for both of these goals to be met.

Inventory data from spring 2009 and fall 2009 is presented for both mentees and a control group. Retention issues are also discussed, as concept retention has been measured both in the short-term (several weeks) and long-term (approximately four months over the summer recess). Data indicates that, when presented in an effective manner, correct answers on I.I. questions increase from roughly 50% to between 80 and 100%. Those questions showing less significant improvement are also discussed. Not surprisingly, P.C.I. data is more varied, as questions on the P.C.I. require algebraic notation or computation. These results require additional interpretation that accounts for mentees' levels of mathematics education and abilities. Results from both will guide more effective future implementations of DREAM.

In the fall 2009 AHS College Preparatory Survey, all but one senior that had previously participated in DREAM (seven of eight) indicated that they were interested in pursuing engineering. The last wished to study architecture. This indicates the success of DREAM in presenting physics concepts in an exciting and intellectually stimulating format.

Introduction

Over the range of years form 2006-08, 25% of Houston's population was African American and 37% Hispanic or Latino[1]. Students from these groups, however, are generally underrepresented in college, specifically in the STEM fields. Nationally only 11% of baccalaureate degrees in engineering were conferred to these two groups in 2006[2]. Over 30% of both the African

American and Hispanic/Latino population in the US is under the age of 18[3,4]. Therefore, extending knowledge of STEM fields and the college admissions process to these large, young populations at critical points in their educational development can have a significant impact on increasing the percentages of underrepresented students in STEM.

DREAM (Designing with Rice Engineers—Achievement through Mentorship) addresses this by challenging underrepresented minority students at three high schools in Houston to complete a design project rooted in physics and engineering concepts. Over 5-7 weeks, Rice University students (mentors) travel to Austin High School (AHS), KIPP High School (KIPP), and Chavez High School (CHS) and guide these students (mentees) on their projects. Once a week, a group of two to four mentees meets with their mentor to work on their project, ask questions about college, and even develop friendships. The extensive contact hours received by the mentees allow for the promotion of physics concepts and the STEM fields.

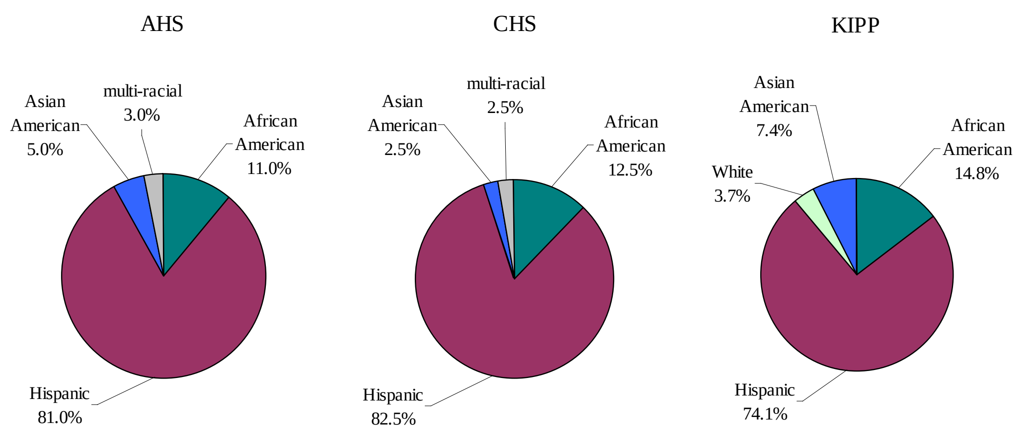


Figure 1: Demographics of DREAM mentees from spring 2009

The demographics of the participants are never pre-determined by the program, and as such the DREAM mentee demographics largely reflect the school demographics. At Austin High School (AHS), African Americans and Hispanics make up, on average, 96% of the participants in the DREAM program, historically. In spring 2009, 95% of AHS mentees identified themselves as Hispanic, African American and/or multiracial. Similarly, 97.5% of Chavez DREAM mentees identified themselves in one or more of these three groups in spring 2009. KIPP had the smallest percentage of underrepresented minorities in the DREAM program, with just under 90% identifying themselves as either African American, Hispanic or both. The specific demographic breakdowns are shown in Figure 1. A major goal of DREAM is to infuse a large percentage of underrepresented minorities into STEM fields, making these schools ideal partners. Also, participation by girls is quite high in DREAM, particularly in schools where students self-select to participate. AHS has averaged 45% female mentees from fall 2007 through spring 2009. In the first semester of DREAM at KIPP (spring 2009), 48% of the mentees were female. Interestingly, at CHS only 28% of mentees were female in spring 2009. At CHS, DREAM takes place in Academy of Engineering (AoE) classrooms, therefore the mentees must select to participate in the AoE curriculum to participate in DREAM. Selection issues are addressed in a companion paper "Motivating Minority High School Students for Futures in Engineering through DREAM (Designing with Rice Engineers – Achievement through Mentorship)[5]."

DREAM addresses all the stipulations presented in a recent Oak Ridge National Laboratory study for creating a successful outreach program[6], particularly in evaluating both its mentors and mentees. A recent paper by Campo *et al*.[7] discusses early outcomes of DREAM at AHS. Since, the DREAM program has expanded to also include KIPP and CHS, allowing for a more thorough and diverse study.

Two particular areas of academic performance have been tracked for the last two years. Through Intuition Inventories (I.I.) and Physics Concepts Inventories (P.C.I.) mentees' knowledge of physics concepts is measured at both the beginning and end of the program. Similarly, mentees' awareness of college admissions processes, including financial aid and scholarship opportunities, is measured through Perception and Environment Surveys (P.E.S.). The inventories and surveys track improvements of mentees throughout the DREAM program. Mentee inventory scores are discussed here. Initial findings from the P.E.S. have been presented in the 2009 ASEE paper "Mentoring to Impassion the Study of Engineering in Underrepresented High School Students via a Design Mechanism" by Campo *et al*.,[7] and the 2009 Sigma Xi conference poster titled "DREAM: Attracting Underrepresented High School Students to Engineering through Mentoring and Design" presented by Kong, Salies and Garland[8]. P.E.S. data indicates DREAM's success in impassioning mentees for study in STEM fields. Recent P.E.S. studies are the subject of a companion paper[5].

Before and after each semester of DREAM, mentees complete inventories evaluating their intuition and their physics knowledge. This paper discusses the data obtained from the DREAM mentees through these inventories. First, the methods of data collection are presented. The results of the inventories are then discussed. I.I. data, which measures physical insight, is considered first. Then P.C.I. data, which places more emphasis on algebraic representation and quantitative analysis, is considered in two parts: the multiple-choice section and the short answer segment. Lastly, additional analyses are performed on data from KIPP, where the most significant control data has been collected. The P.C.I. and I.I. data discussed here is a testament to DREAM's success in instilling an understanding of basic physics concepts.

Methods of Data Collection

To track the DREAM program's effectiveness at imparting physics knowledge in the mentees, inventories were systematically administered at Austin High School, Chavez High School, and KIPP Houston High School.

These inventories were intended to span the field of topics that occurred in the design projects of both the spring 2009 and fall 2009 semesters, to measure long-term retention. The inventories were broken into two parts. The first page was designed as an Intuition Inventory (I.I.). The I.I.'s from spring 2009 and fall 2009 are nearly identical, as shown in the Appendix. These served to gauge the mentees' physics intuition without computation or algebraic representation. The primary topic covered on the I.I. was the invariance of gravitational acceleration. For example, mentees were asked to consider two blocks of different mass that were dropped from the same height. Using this information, they were to predict which block would fall first.

The second page of the inventory was devoted to more numerical and algebraic representations of physic concepts. As such, it has been termed the Physics Concepts Inventory (P.C.I.). The P.C.I. gauged mentees' knowledge of kinetic and potential energy concepts. Mentees were asked to produce formulas for kinetic and potential energy. An example of one of the question asked on the P.C.I. concerned two objects of different masses, placed at different heights. Mentees were asked to determine which of the two masses possessed a larger potential energy.

The inventories were administered systematically at the three high schools to track mentees' improvements in basic physics concepts. The inventories were given out at different times for the three schools, as summarized in Table 1**.**

Cohort	Before DREAM S09	DREAM Day S09	3 Weeks After DREAM S09
Austin Mentees	**X**	**X**	
Chavez Mentees	**X**	**X**	
KIPP Mentees	**X**	**X**	**X**
KIPP Control	**X**		**X**

Table 1: Times when inventories were administered at the three high schools

As illustrated by Table 1, mentees at all three schools were given inventories at the beginning and end of the DREAM program. KIPP also had inventories administered at the beginning and end of the program to a control group in order to ensure that mentee improvements could be attributed to the DREAM program. For the spring 2009 semester, the only DREAM participants at KIPP High School were freshmen. As such, the control group was selected to be the entire balance of the freshmen class at KIPP.

Final inventories at KIPP were given three weeks after DREAM Day, to both the mentees and control group, to evaluate the mentees' short-term retention of the material several weeks after the program had ended. The mentees' long-term retention of the material is also being measured. In order to test the retention rate on a long-term scale, the same concepts (invariance of gravitational acceleration, kinetic energy, potential energy) were used for the fall 2009 design project. As such, inventories were administered to KIPP students at the beginning of the fall 2009 program, and the retention rate of these same concepts was measured for the six returning KIPP mentees from the spring 2009 program.

Assessment and Discussion

The I.I. and P.C.I. were administered to all mentees at AHS, CHS, and KIPP. At KIPP the entire freshman class took the inventories before DREAM started in spring 2009. After, a subset of 27 students from this group became DREAM mentees, leaving a control group of 123 students. The I.I. results are analyzed first, followed by the P.C.I., the later of which contains multiple-choice and short answer portions. Finally, the supplemental control and short-term retention inventories that were administered at KIPP are discussed.

Intuition Inventory (I.I.)

The I.I., included in the Appendix, was comprised of three multiple-choice questions dealing with the invariance of gravitational acceleration. Some interesting things can be noted about the mentees' performance on the I.I. portion. First and foremost, the overall performance of the mentees from the initial inventory to the DREAM Day inventory increased. Consider the subsequent tables that sum up the percentage of correct answers at the three high schools before and after DREAM Day. Throughout, numbers in parenthesis indicate the sample size.

AHS	Question 1	Question 2	Question 3
Initial (37)	51%	59%	43%
Dream Day (30)	87%	83%	97%

Table 2: Correct responses of AHS mentees on the I.I. at the beginning and end of the program (S09)

CHS	Question 1	Question 2	Question 3
Initial (39)	21%	56%	31%
Dream Day (39)	87%	54%	85%

Table 3: Correct responses of CHS mentees on the I.I. at the beginning and end of the program (S09)

KIPP	Question 1	Question 2	Question 3
Initial (27)	41%	67%	22%
Dream Day (26)	96%	50%	96%

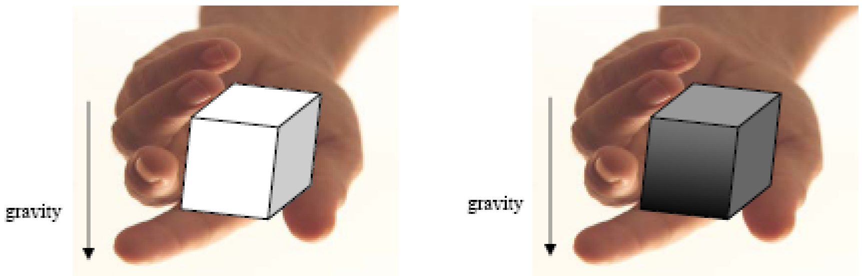
Table 4: Correct responses of KIPP mentees on the I.I. at the beginning and end of the program (S09)

It is clear from Table 2 that the percentage of correct answers increased on all three questions from the first inventory to the DREAM Day inventory for AHS mentees. KIPP and Chavez improved on the whole on the I.I. as well. Specifically, the number of right answers on questions 1 and 3 increased dramatically from the first inventory to the DREAM Day inventory. On question 1, there was an average increase of 52% in right answers for the three schools, which include 95 total mentees that participated in their respective DREAM Days. Similarly, the average increase of correct answers for the three schools on question 3 was 60%. This shows that DREAM was effective at imparting knowledge regarding the invariance of gravitational acceleration and the decoupling of motion to the mentees at all schools.

It should be noted that the performance on question 2 actually decreased slightly for Chavez and KIPP. Figure 2 shows that question 1 of the I.I. deals with dropping two blocks of different masses from the same height, and asks which will fall first. Question 2 says that two blocks are again at the same starting height. Now however, one block is dropped whereas one block is thrown down. The mentees are asked to predict which block will land first.

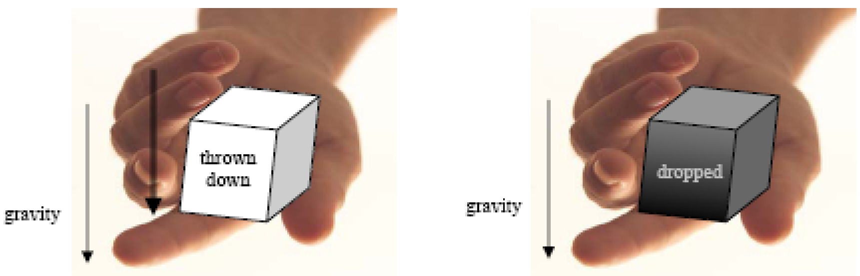
The possible reasons for the reduction in correct answers have been speculated, and the most likely theory is as follows. Initially the mentees' intuition led them to believe that the more dense block would fall fastest in question 1, and that the block that was thrown would fall fastest in question 2. Throughout the course of the program, the notion of the invariance of gravitational acceleration was then discussed at length. Thus, when mentees were confronted with question 2 on DREAM Day, they thought that the invariance of gravitational acceleration would lead **both** blocks to land at the same time in both questions 1 and 2.

1) Two blocks are dropped from the same height. They are the same size, but the black block has more mass (it is more dense). Which statement is true?



a) the black block hits the ground first
b) the white block hits the ground first
c) the blocks hit the ground at the same time
d) not enough information

2) Now the black block is dropped, but the white block is thrown down. The blocks are the same size, but the black block has more mass (it is more dense). Which statement is true?



a) the black block hits the ground first
b) the white block hits the ground first
c) the blocks hit the ground at the same time
d) not enough information

Figure 2: Questions 1 and 2 from the spring 2009 Intuition Inventory

In other words, there was a breakdown in the educational process at two of the schools. When the mentors told the mentees that "all things fall at the same rate due to gravity," the mentees misunderstood this to mean that all objects will fall in the same time, independent of their initial velocities. Clearly, the mentees' revised belief was incorrect. However, it is in some ways more telling than the improved performance on the other questions.

This reflects a miscommunication between the DREAM mentors and the mentees. The process was successful in improving mentees first level of understanding, namely that two objects of different densities, dropped simultaneously should fall in the same time, but confused their higher order understanding of the more complicated problem where initial velocities are not the same. Because of this, the fall 2009 discussions on the invariance of gravitational acceleration were tailored to ensure that the misconceptions were dispelled. Specifically, the idea of imparting an initial force (and therefore an initial velocity) on one block, as compared to just dropping the other, was discussed. Thus, the misconception that led to decreased performance in the spring 2009 program allowed for fine-tuning the manner in which these concepts were taught in subsequent semesters.

Interestingly, mentees at Austin High School showed significant improvement on question 2. This is attributed to a series of impromptu recitation sections that took place at AHS, where the setting is unstructured. Participation in DREAM is totally voluntary at AHS, and there is no fixed duration for each meeting (it is only required that these be at least one hour), and often sessions go for 90 minutes or more based on the interest of the mentees. Therefore, mentors have more freedom to informally teach subsets of the group of mentees in small blocks of time. Since these impromptu lessons took place at Austin High School and not at the two other schools, this best explains the dramatic increase in percentage of correct answers for question 2. Clearly, repetition of more difficult material, in a variety of settings, is effective. For example, mentors at AHS often turned these impromptu lessons into games with small teams competing to answer questions for points. Such methods may be inserted throughout the program at strategic points in the future, though noncompetitive lessons are also important. This also highlight the importance of high contact hours, and therefore the program will always be run for a minimum of seven weeks in the future.

Physics Concepts Inventory (P.C.I.)

The results from the P.C.I. were also measured and are now discussed. The P.C.I. was made up of mass, potential energy, and kinetic energy concepts. It differed from the I.I. not only in the concepts that were tested, but also in the way these concepts were tested. The I.I. was intended to be a check of the mentees' physics intuition, and consequently no calculations were necessary to answer the questions on the I.I. By contrast, the P.C.I. was numerically and algebraically based. As such, mentees were asked to provide formulas for potential and kinetic energy (see the Free Response section below), or to use basic arithmetic to determine which ball had more potential energy (see the appendix for the complete P.C.I.). The P.C.I. was broken up into multiple choice questions and short answer questions, and the following discussion is also split into two sections.

P.C.I. Multiple-Choice

The mentees' performance on the multiple-choice portion of the P.C.I. was also largely encouraging. Consider the following tables that summarize the percentage of correct answers at the three different schools at the beginning and end of the program, where numbers in parentheses indicate the numbers of mentees participating:

AHS	**Question 1**	**Question 2**	**Question 4**	**Question 5**
Initial (37)	62%	78%	16%	24%
DREAM Day (30)	70%	73%	37%	30%

Table 5: Correct responses of AHS mentees on the P.C.I. multiple-choice section (S09)

CHS	**Question 1**	**Question 2**	**Question 4**	**Question 5**
Initial (39)	51%	77%	15%	33%
DREAM Day (39)	67%	74%	31%	22%

Table 6: Correct responses of CHS mentees on the P.C.I. multiple-choice section (S09)

KIPP	**Question 1**	**Question 2**	**Question 4**	**Question 5**
Initial (26)	38%	53%	4%	27%
DREAM Day (26)	84%	65%	38%	23%

Table 7: Correct responses of KIPP mentees on the P.C.I. multiple-choice section (S09)

Several things may be noted from the multiple-choice results for the three schools. First, and of greatest importance, all three schools show general overall improvement, though certain questions showed decreases in correct answers. These exceptions include question 2 for Austin High School and question 5 for Chavez High School. Decreases in question 2 for CHS and question 5 for KIPP are not significant. It is noteworthy also to mention that the percentage decrease of correct answers for these questions is small compared to the percentage increase in correct answers on nearly all other questions.

There are other things of interest to take from this. While there were significant improvements, particularly in questions 1 and 4, the increases were still below desired targets. The average percentage increase on the P.C.I. multiple-choice segment was much smaller than the average increase on the I.I. for the three schools. The average increase in correct answers on question 1 of the P.C.I. was 23% for the three schools. Similarly, the average increase in correct responses on question 4 was 23% for the three schools. These are small percentage increases compared to the 52% average increase in correct answers for question 1 of the I.I., and 60% average increase in overall correct answers on the I.I.

This can be explained in part by the nature of the mentoring that occurs at the three schools. The mentoring takes place on very conceptual and intuitively based levels. As such, it is expected that the intuition portion of the inventory (I.I.) would produce better results than the numerical/algebraic portion of the inventory (P.C.I.). The greater improvement observed on the I.I. validates this idea. This also gives DREAM an opportunity for future improvement. In particular, since the mentees are doing better on the I.I. part of the inventories, it is clear that additional focused mentoring on numerical and algebraic topics is needed.

Taking on a more numerical/algebraic approach will need to be implemented differently at each of the schools because of the wide range of academic backgrounds of the mentees. For example, AHS mentees span 9th - 12th grade. As such, the range of courses taken by the mentees is very large. Some mentees are in their first year of algebra, whereas others are in AP Physics. Fortunately this variation can be addressed relatively easily. Because of the framework of DREAM, Rice mentors should be able to tailor their teaching to the academic background of the small group of mentees that they are working with for the semester. Similarly, as the DREAM program at KIPP and CHS begins to expand into the different grade levels, the same approach of tailoring the material to the background of the student will be taken.

P.C.I. Free Response

This portion of the inventory dealt with algebraic representations of physics concepts. Specifically, the mentees were asked to provide the formulas for potential energy and kinetic energy. The scoring for this portion of the inventory was done slightly differently than for the other sections. In order to account for students who gave answers that were reasonably close to the correct answer, partial credit was given. For example, answers for kinetic energy such as $KE = \frac{1}{2} mv$ were awarded partial credit. The results for the three schools are given below.

AHS	Question 3a			Question 3b		
	correct	**partially correct**	**incorrect**	**correct**	**partially correct**	**incorrect**
Initial (37)	14%	32%	54%	11%	41%	49%
DREAM Day (30)	20%	40%	40%	20%	37%	43%

Table 8: Results on the P.C.I. free response for Austin High School mentees (S09)

CHS	Question 3a			Question 3b		
	correct	**partially correct**	**incorrect**	**correct**	**partially correct**	**incorrect**
Initial (39)	5%	31%	64%	3%	34%	62%
DREAM Day (39)	56%	2%	41%	0%	54%	46%

Table 9: Results on the P.C.I. free response for Chavez High School mentees (S09)

KIPP	Question 3a			Question 3b		
	correct	**partially correct**	**incorrect**	**correct**	**partially correct**	**incorrect**
Initial (26)	0%	46%	54%	0%	38%	62%
DREAM Day (26)	0%	46%	54%	0%	38%	62%

Table 10: Results on the P.C.I. free response for KIPP High School mentees (S09)

The percentage of answers meriting at least partial credit went up on both questions for Austin High School and Chavez High School. Interestingly, KIPP High School saw no improvement for either question. It should be noted that the same trend holds true for the free response P.C.I. segment as in the Multiple-Choice P.C.I. portion. Namely, the average percentage increase of answers meriting partial credit was small compared to the average percentage increase of correct answer on the I.I. Question 3a had an 18.5% average increase in answers receiving partial credit, and Question 3b had an 11% increase in answers meriting partial credit. Again, this increase is small compared to the 52% and 60% average increases in correct answers on questions 1 and 3 of the I.I., respectively.

This may again be attributed to the nature of the mentoring that took place. As stated above, the mentoring was skewed toward providing mentees with better intuition about the fundamental physics concepts involved in the project. This resulted in drastic improvements on the I.I. As such, it is hoped that incorporating a greater focus on the numerical and algebraic aspects of physics concepts will likewise improve the mentees' performance on the P.C.I. In this way, mentees will be instilled with a greater holistic knowledge of physics.

Control Group at KIPP

In order to ensure that improvements in mentee performance could be attributed to DREAM, a study was performed on a control group at KIPP High School. The participating DREAM mentees for the spring 2009 semester were all freshmen. As such, the control group was selected to be the entire freshman class. This control group of 111 and 123 students completed inventories at the beginning and end of the program, respectively, simultaneous with the short-term retention study of the KIPP mentees. The results for the I.I., as well as the multiple-choice and free response P.C.I. are given in the following tables.

Control Group	Question 1	Question 2	Question 3
Initial (111)	20%	51%	31%
Final (123)	43%	57%	26%

Table 11: Correct responses of the KIPP control group on the I.I. (S09)

On the initial I.I., 31% of the control group answered a fundamental question on projectile flight and motion decomposition correctly. On the final I.I, 26% of the control group answered that same question correctly—a decrease of 5%. In contrast, mentees showed a 74% increase in correct responses over this period.

Control Group	Question 1	Question 2	Question 4	Question 5
Initial (111)	44%	59%	10%	25%
Final (123)	67%	68%	12%	28%

Table 12: Correct responses of the KIPP control group on the P.C.I. multiple-choice (S09)

On the fundamental question regarding kinetic energy on the P.C.I., correct answers from the control group increased slightly from 10% to 12%. In comparison, correct answers from mentees increased from 4% to 38%. Mentees at KIPP self-select to participate in DREAM from a multitude of after-school extracurricular activities. Mentees involved in DREAM are not selected on academic merit, yielding an inherent representative control group for comparison at KIPP. Issues of selection at all three schools will be discussed at length in a future paper.

Control Group	Question 3a			Question 3b		
	correct	**partially correct**	**incorrect**	**correct**	**partially correct**	**incorrect**
Initial (111)	0%	42%	58%	0%	42%	58%
Final (123)	2%	31%	67%	4%	31%	65%

Table 13: KIPP control group performance on the P.C.I. free response (S09)

For all of the results given in the three preceding tables, the percentage change in correct answers is below 9% except for question 1 on the I.I. and question 1 on the P.C.I, which both saw a 23% increase in correct answers from the initial to final inventory. In comparison, correct answers from KIPP DREAM mentees increased from 41 to 96% on question 1 of the I.I., and from 38 to 84% on question 1 of the P.C.I.

The improvement in the results of the control group can be attributed to the discussions KIPP teachers had with all freshmen immediately after the initial inventory was administered. In particular, they discussed the first questions of each inventory, and were very effective as this single lesson was retained by a measurable portion of the control group two months later. The significant additional improvement measured in the mentees can be attributed to reinforcing these concepts through hands-on activities and repeated lessons from mentors. In fact, over the spring 2009 semester, more than 1,217 contact hours were achieved between the mentees and mentors, as illustrated in Figure 3. This is a staggering amount of mentoring time that allowed for the hands-on reinforcement of the material. Actual contact hours were greater because, primarily at AHS, after-school mentoring sessions often ran for well over the one hour minimum.

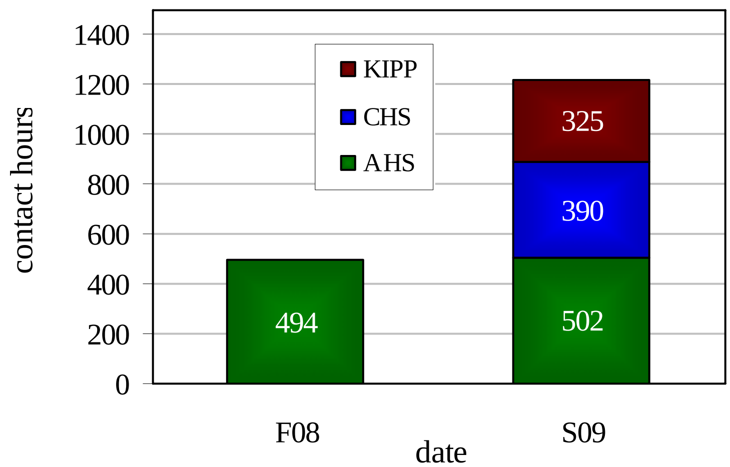


Figure 3: Mentee contact hours with mentors, by school (conservative)

This idea of hands-on reinforcement to foster the learning process is supported by the recent work of Bayles and Monterastelli[9]. Hands-on activities create an exciting context to learn math and physics, and are effective at least as early as in middle-school years[10]. Furthermore, because a great deal of time was spent with the mentees, they showed improvement across a broader range of questions. As such, a large portion of the increases in performance by the DREAM mentees can be attributed to the DREAM program.

These results indicate that changes in the performance of the control group on all questions, except the first on each inventory, are negligible, while KIPP mentees demonstrate significant improvements in both intuition and conceptual understanding. Thus the mechanisms utilized in DREAM can instill mentees with physics knowledge, one of the over-arching goals of the program. Since the control group remained relatively stagnant in their performance, improvements in the physics knowledge of mentees can be directly attributed to the DREAM program. As a result, DREAM is aiding to prepare mentees for the curricula associated with undertaking study in STEM fields.

Retention of Concepts at KIPP

Another set of inventories was administered to the DREAM mentees at KIPP at the end of the spring 2009 semester (1 month after the completion of the DREAM program). In this way, the mentees short-term (ST) retention of the concepts was tested. The results for the initial, DREAM Day, and ST retention inventories are displayed below.

KIPP	Question 1	Question 2	Question 3
Initial (27)	41%	67%	22%
Dream Day (26)	96%	50%	96%
ST Retention (26)	96%	46%	65%

Table 14: Correct responses on the I.I. for KIPP mentees, including the short-term retention inventory (S09)

Recall that correct answers on a fundamental projectile flight question on the I.I. improved from 41% to 96% for KIPP mentees. On the third inventory in the ST, the number of correct answers for this question stayed at 96%, indicating a perfect retention rate.

KIPP	Question 1	Question 2	Question 4	Question 5
Initial (26)	38.5%	53.9%	3.85%	26.9%
DREAM Day (26)	84.6%	65.4%	38.5%	23.1%
ST Retention (26)	92.3%	69.2%	30.8%	15.4%

Table 15: Correct responses on the P.C.I. Multiple-Choice for KIPP mentees, including short-term retention (S09)

Recall that on the P.C.I, correct answers on a question regarding kinetic energy improved from 4% to 38% from the initial P.C.I. to the P.C.I. distributed on DREAM Day. On the third P.C.I. the number of correct answers decreased to 31%. Thus, while the retention rate was not perfect in this case, results were still significantly better than in the initial survey.

KIPP	Question 3a			Question 3b		
	correct	partially correct	incorrect	correct	partially correct	incorrect
Initial (26)	0%	46%	54%	0%	38%	62%
DREAM Day (26)	0%	46%	54%	0%	38%	62%
ST Retention (26)	0%	54%	46%	0%	35%	65%

Table 16: Free-Response results for KIPP mentees, including the short term retention inventory (S09)

Now that a few specific examples have been considered, the retention inventory is compared to the initial inventory in a broad sense. It is seen from Tables 13-15 that the performance on the retention inventory was better than the performance on the initial inventory on all of the questions except for question 2 on the I.I., question 5 on the multiple-choice P.C.I., and question 3b on the free response P.C.I. It should be noted that question 3b on the free response saw only a 3% decrease in performance, which is negligible. For question 2 on the I.I. and question 5 on the multiple-choice P.C.I., the disparity in performance is to be expected, as performances were worse on DREAM Day as well, as explained in the Assessment and Discussion section. Thus, performance on the whole was better on the retention inventory than on the initial inventory, which suggests that DREAM is successful in helping the mentees retain the material.

Now the performance on the retention inventory will be compared to the performance on the DREAM Day inventory. The performance in this area is rather mixed. The same percentage of correct answers was observed on question 1 of the I.I. Interestingly, the percentage of answers actually increased from the DREAM Day inventory to the retention inventory for questions 1 and 2 of the multiple-choice P.C.I. and on question 3a of the free response P.C.I. However, for the remaining 5 questions, the percentage of correct answers decreased from the DREAM Day inventory to the retention inventory. The results suggest that mentees knew the material better than before their involvement with DREAM, but not as well as when it was freshest in their minds on the DREAM Day inventory. Thus, while retention was not perfect from DREAM Day to three weeks after, there was still overall improvement, compared to pre-DREAM.

Long-term Retention

In order to continue to track the mentees ability to retain basic physics information, the I.I. and P.C.I. surveys for the fall 2009 semester dealt with the same concepts as in the spring 2009 semester. In this way retention over several months (long-term) were studied. Furthermore, transcript data has also been collected and cross-correlations between Inventory scores (retention) and relevant classes, such as Physics or Integrated Physics and Chemistry (IPC) will be discussed in a future publication.

In order to complete this study on retention of the material, inventories covering the same fundamental physics concepts were administered at the beginning of the fall 2009 program. By doing this, DREAM was able to measure the mentees' ability to retain these concepts after several months without instruction, including summer recess. Thus, the inventory was administered to the six returning mentees at KIPP, and their results for the fall 2009 inventory were compared to their results on the previous inventories.

First a few words should be said about the number of returning mentees at KIPP, because communication breakdowns are among the biggest challenges to outreach programs, and this highlights such a breakdown. In order to understand the low retention rate of participants, DREAM mentors spoke with the Student Activities Coordinator at KIPP and learned that several factors went into the small number of returning students. First, there was not a meeting at the beginning of the fall 2009 semester to announce that the DREAM program was occurring again. As such, many of the students were unaware that the program was being held for the second consecutive semester. In addition, some of the previous mentees thought that DREAM was only a one-semester program that could not be taken more than once. As such, some of the mentees who knew about the fall 2009 DREAM program did not enroll for this reason. With these problems brought to light, measures were taken to boost retention rates in spring 2010.

Specifically, DREAM was promoted much more actively for the spring 2010 semester. After addressing the mentees' misconceptions that were introduced in the previous paragraph, thirteen of the original twenty-six students returned for the spring 2010 semester. After the conclusion of the spring 2010 program, the returning mentees' retention of information will be assessed and DREAM's effectiveness at imparting lasting physics knowledge will be reconsidered.

For now, the results of the six returning mentees from the fall 2009 semester are summarized in the following tables. For comparison's sake, only the questions that were the same for all of the inventories are considered.

KIPP Retention	Question 1	Question 2	Question 3
Initial (S09)	50%	83%	0%
Dream Day (S09)	100%	67%	100%
Retention (S09)	67%	17%	50%
Fall 2009	50%	67%	50%

Table 17: Results on the I.I. for the six returning mentees. Note, the questions are the same for all inventories.

KIPP Retention	Question 4/3 for fall 2009	Question 5/4 for fall 2009
Initial (S09)	0%	17%
DREAM Day (S09)	67%	17%
Retention (S09)	33%	0%
Fall 2009	33%	33%

Table 18: Results on the multiple-choice P.C.I. for the six returning mentees. Note: the only two questions that were the same were the last two. Thus, question 4 on the spring 2009 P.C.I. corresponds to question 3 on the fall 2009 P.C.I., and question 5 on the spring 2009 P.C.I. corresponds to question 4 on the fall 2009 P.C.I.

	Question 3a/ 2a for fall 2009			Question 3b/ 2b for fall 2009		
	correct	partially correct	incorrect	correct	partially correct	incorrect
Initial (S09)	0%	17%	83%	0%	33%	67%
DREAM Day (S09)	0%	33%	67%	0%	50%	50%
Retention (S09)	0%	17%	83%	0%	0%	100%
Fall 2009	0%	0%	100%	0%	0%	100%

Table 19: Results on the free response P.C.I. for the six returning mentees. Questions 3a and 3b on the spring 2009 P.C.I. correspond to questions 2a and 2b on the fall 2009 P.C.I., respectively.

As should be expected with such a small sample size, the results are mixed. Improvements from the initial inventory (pre-DREAM, spring 2009) to the fall 2009 inventory are observed on question 3 of the I.I., as well as both of the questions for the multiple-choice P.C.I. In all of the other questions, however, the percentage of correct answers was lower in the fall 2009 inventory than in the initial inventory. Again, no conclusions can be drawn because of the small sample size. Now that the number of returning mentees at KIPP is steadily rising, and steps will be taken to assess mentees' long-term knowledge of basic physics concepts.

Future Work

Several things were learned from the assessment, which will guide future implementations of DREAM. Namely, there was a much larger increase in performance on the I.I. as compared to the P.C.I. This suggests that the nature of the mentoring needs to be altered. Namely, efforts will be made to incorporate a numerical and algebraic approach to supplement the teaching of physics intuition. This instruction will take the form of mini-lectures by Rice faculty, mentors and student leaders of supporting clubs, both during DREAM and on DREAM Day. In this way, DREAM will be able to facilitate well-rounded understanding of physics.

Lastly, the long-term retention of the KIPP students was not adequately tested because of the small number of returning mentees. Efforts will be made to ensure that more mentees are retained throughout the following semesters so that a more thorough study of the long-term retention of these concepts may be conducted.

Conclusion

The preceding data indicates that DREAM is successful in achieving its two goals of increasing interest in STEM fields, as well as preparing high school students for the curricula they will face upon enrolling into these STEM fields. Nearly 90% of Austin High School seniors that have participated in DREAM recently indicated an interest in studying engineering in college, and significant improvements in physics knowledge have been measured in every semester since the inception of DREAM.

The DREAM program successfully improves the physics knowledge and college preparation of mentees. Through the mechanisms of a design competition and extended mentorship DREAM is able to better prepare these underrepresented students for entering college, as seen by the improvements in the mentees' inventory scores over the duration of the program. These improvements are credited to the DREAM program by comparing mentees' physics knowledge to a control group at KIPP High School, which did not improve significantly over the duration of the program.

Specifically the mentees' improvements in understanding the invariance of gravitational acceleration, the decoupling of motion, and kinetic and potential energy speak to the success of DREAM. Mentees were able to understand and remember these concepts. The design project focused on the understanding of gravitational potential energy, and conversion of this potential to kinetic energy. The mentees were able to correctly identify physics concepts in this project, and improved their understanding through the hands-on activities. Improved knowledge, in conjunction with mentees hands-on experiences and enhanced understanding of college admissions and the STEM fields, will greatly aid mentees in taking the next step to a college education in engineering.

Acknowledgement

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Appendices

Included in the appendices are the II and PCI from both spring 2009 and fall 2009, as well as the spring 2009 design competition rules.

Name: ____________________   Grade (circle one):   Freshman   Sophomore   Junior   Senior   Date: ________________

Are you in IPC, or have you completed IPC (circle one)?   yes   no   already took IPC

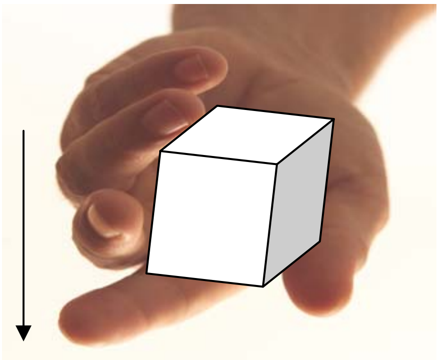
Have you taken any additional physics classes (circle one)?   yes   no

If yes, how many years of additional physics have you had (circle one)?   less than 1 year   1 year   more

Please answer the questions as best you can. This may be material you haven't ever covered in class, so it is ok if you don't know the answers. This won't be graded, and your teachers and parents/guardians will never see the results. This is only to see if the DREAM project is effective at introducing new concepts. Please try your best.

1) Two blocks are dropped from the same height. They are the same size, but the black block has more mass (it is more dense). Which statement is true?

gravity



gravity

a) the black block hits the ground first

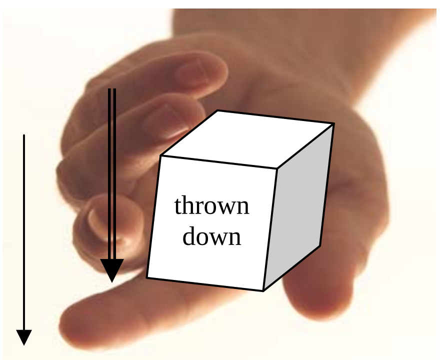
b) the white block hits the ground first

c) the blocks hit the ground at the same time

d) not enough information

2) Now the black block is dropped, but the white block is thrown down. The blocks are the same size, but the black block has more mass (it is more dense). Which statement is true?

gravity



gravity

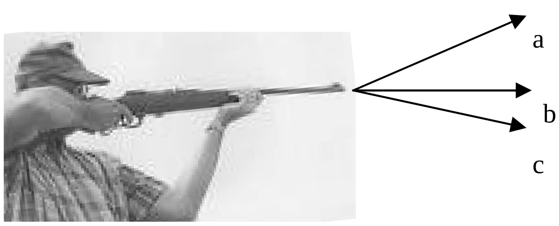
a) the black block hits the ground first

b) the white block hits the ground first

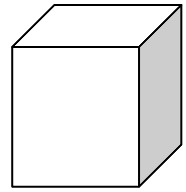
c) the blocks hit the ground at the same time

d) not enough information

3) A man wants to shoot King Kong, who is in a tree. The man is standing on a ledge, so he and the ape are initially at the same height. The man knows that as soon as he shoots, the ape will let go and drop from the tree at the exact same time. Which direction should the man aim (a, b, or c) so that he hits King Kong as he is falling from the tree (circle one)?



1) The block shown has volume V, and mass m.



What are the units on volume V (circle one)?

a) length
b) length × length
c) grams
d) seconds
e) length × length × length

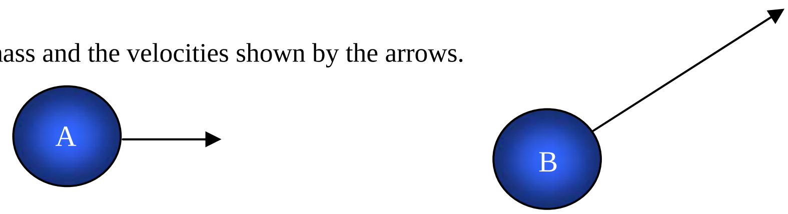
2) What has more mass, a train or a car (circle one)?

a) train
b) car
c) both have the same mass
d) not enough information

3) a) What is the formula for potential energy of something which has mass M and height H? __________

b) What is the formula for kinetic energy for something which has mass M and velocity V? __________

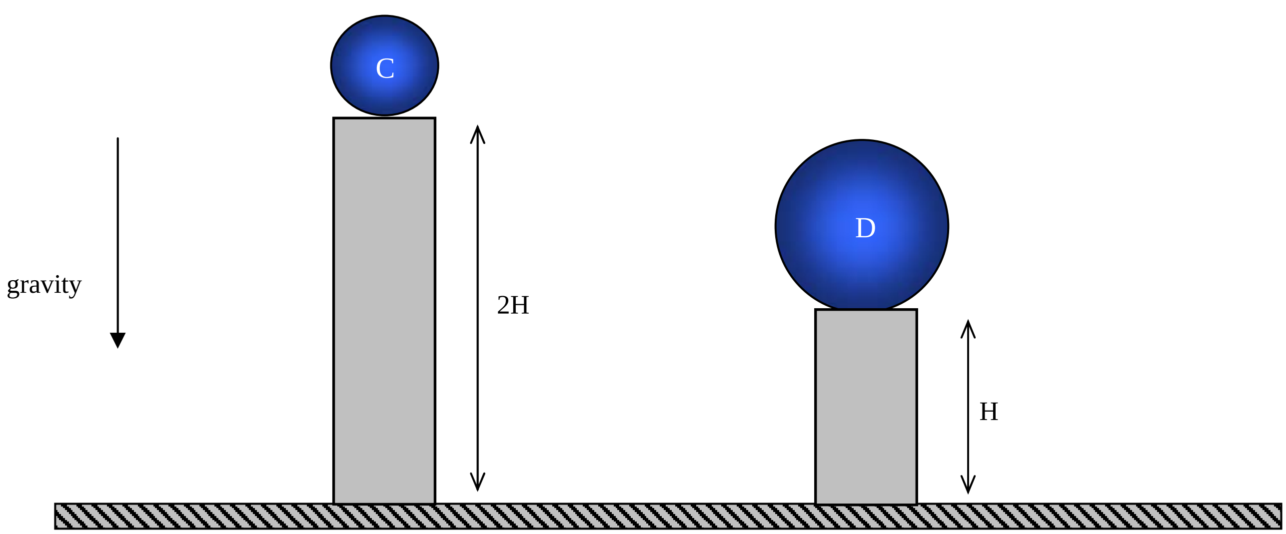
4) Balls A and B have the <u>same</u> mass and the velocities shown by the arrows.



Which statement is true (circle one)?

a) ball A has more kinetic energy
b) ball B has more kinetic energy
c) they have the same kinetic energy
d) not enough information

5) Ball D has <u>three times more mass</u> than ball C. Ball C is <u>twice as high</u> as ball D.



Which statement is true (circle one)?

a) ball C has more potential energy
b) ball D has more potential energy
c) they have the same potential energy
d) not enough information

Are you participating in the DREAM program?   yes   no   If yes, what is your name: ___________________________________

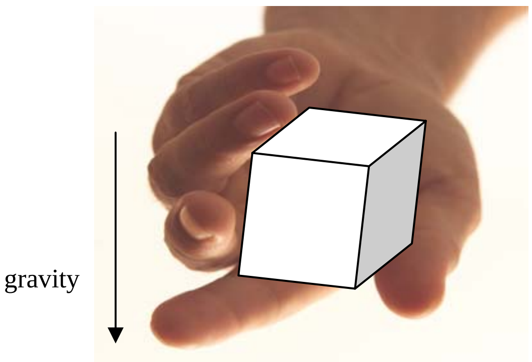
School _____________   Grade (circle one):   Freshman   Sophomore   Junior   Senior   Date: 8/31/2009

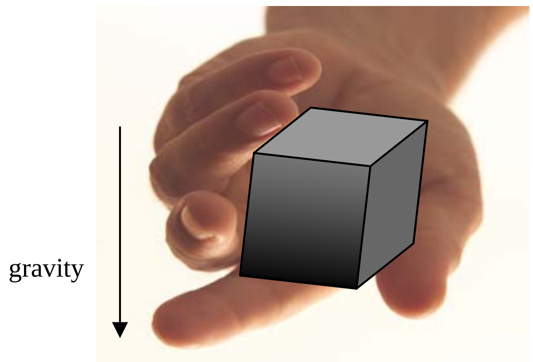
Did you take IPC (Integrated Physics and Chemistry) in middle school (circle one)?   yes   no

What middle school did you attend? _______________________

Please answer the questions as best you can. This may be material you haven't ever covered in class, so it is ok if you don't know the answers. This won't be graded, and your teachers and parents/guardians will never see the results. This is only to see if the DREAM project is effective at introducing new concepts. Please try your best.

1) Two blocks are dropped from the same height. They are the same size, but the <u>black block has more mass</u> (it is more dense). Which statement is true?





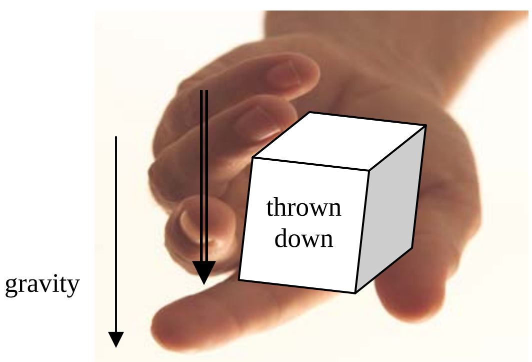
a) the black block hits the ground first

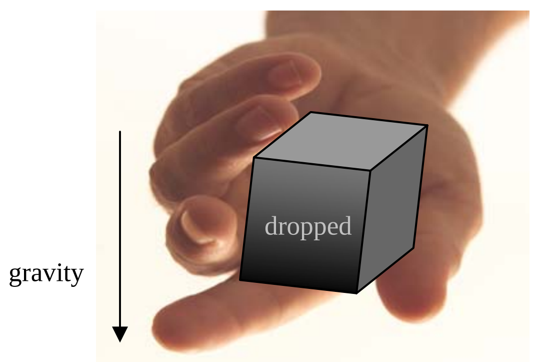
b) the white block hits the ground first

c) the blocks hit the ground at the same time

d) not enough information

2) Now the black block is dropped, but the white block is <u>thrown down</u>. The blocks are the same size, but the black block has more mass (it is more dense). Which statement is true?





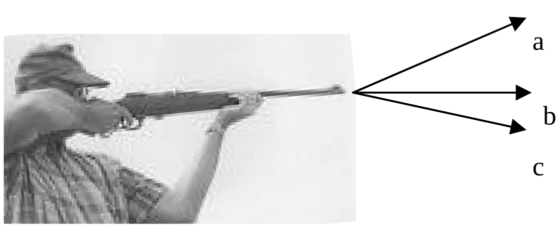
a) the black block hits the ground first

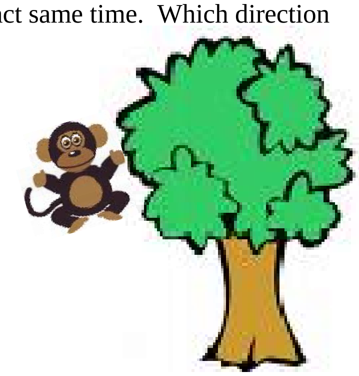
b) the white block hits the ground first

c) the blocks hit the ground at the same time

d) not enough information

3) A man wants to shoot King Kong, who is in a tree. The man is standing on a ledge, so he and the ape are initially at the same height. The man knows that as soon as he shoots, the ape will let go and drop from the tree at the exact same time. Which direction should the man aim (a, b, or c) so that he hits King Kong as he is falling from the tree (circle one)?





1a) What has **<u>more</u>** mass, a train loaded with coal <u>or</u> a car (circle one)?

a) train b) car c) both have the same mass d) not enough information

1b) If the train and car are moving **at the <u>same</u> speed**, which statement is true (circle one)?

a) the train has more momentum

b) the car has more momentum

c) they have the same momentum

d) not enough information

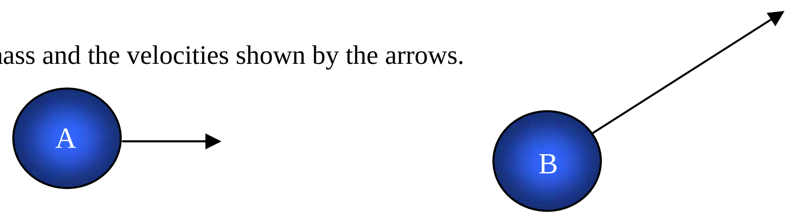
2) An object (for example a coconut) with mass M is falling. At a given instant, it is has height H above the ground, and is moving (falling) with velocity V.

a) What is the equation for the potential energy of the object? P.E. = ________________

b) What is the equation for the kinetic energy of the object? K.E. = ________________

c) What is the equation for the momentum of the object? momentum = ___________

3) Balls A and B have the <u>same</u> mass and the velocities shown by the arrows.



Which statement is true (circle one)?

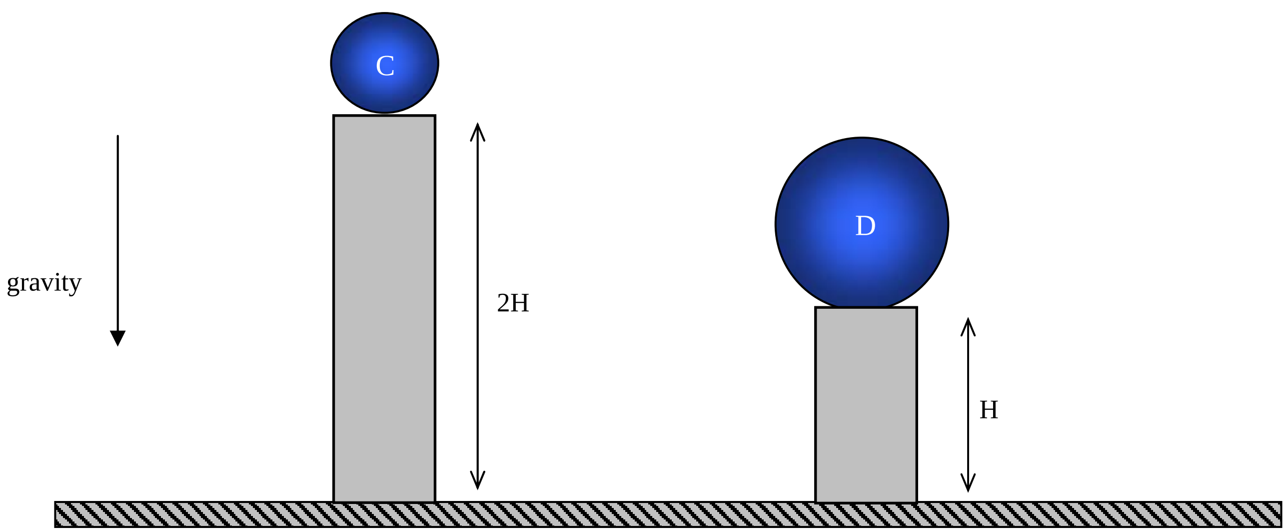
a) ball A has more kinetic energy

b) ball B has more kinetic energy

c) they have the same kinetic energy

d) not enough information

4) Ball D has <u>three times more mass</u> than ball C. Ball C is <u>twice as high</u> as ball D.



Which statement is true (circle one)?

a) ball C has more potential energy

b) ball D has more potential energy

c) they have the same potential energy

d) not enough information

DREAM Program Competition Spring 2009
Don't Miss the Target!

Objective: To get a ping pong ball to hit a target by constructing a self-releasing launching device.

Timeline:

Week 1	Monday, Jan 26 – Friday, Jan 30:	initial skills assessment and brainstorming
Week 2	Monday, Feb 2 – Friday, Feb 6:	building
Week 3	Monday, Feb 9 – Friday, Feb 13:	building and testing
Week 4	Monday, Feb 16 – Friday, Feb 20:	building and testing
Week 5	Monday, Feb 23 – Friday, Feb 27:	improve design
Week 6	Monday, Mar 2 – Friday, Mar 6:	building improved design and testing
Week 7	Monday, Mar 9 – Thursday, Mar 12:	final testing and final modifications

Friday, March 13: ***DREAM Day competition at Rice University***

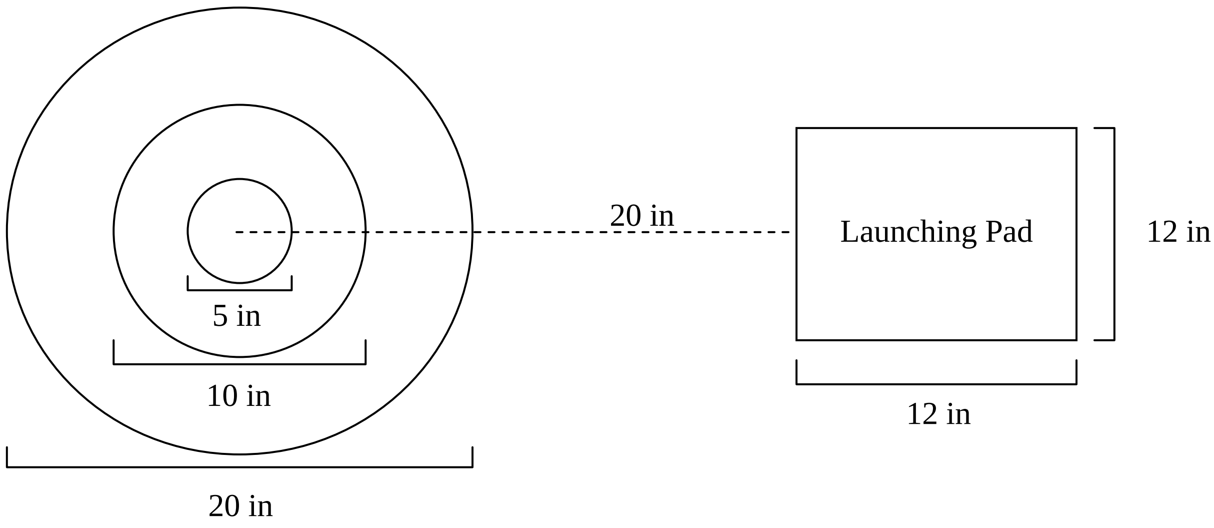
Eligibility:
In order to qualify to win prizes at the DREAM Day competition, ***you must be present for at least 5 of the 7 after school sessions and attend the competition*** itself. To track attendance, we will have a sign in sheet each day – please make sure to sign in so that we know you came!

Design Phase:
You will have seven weeks to design your launching device and build/test it before the final competition day. You will be provided with a box full of materials to do this. *Please write your team name on the box and the lid* so that you know which box is yours. If you need more supplies for the design phase, there are a few boxes with extra supplies in them. This is so that you can build and test more than one device before the real competition. Help yourself to what you need. If what you need isn't there, tell your mentor and they will get it for you the next week. However, keep in mind that on competition day you will only have one set of supplies and will not be granted extra materials.

Competition Day:
The Competition DREAM Day will be split into two periods: construction and testing.

Construction:
On competition day, you will have to build your Launching Device from scratch using the provided materials (see Materials List). You will have exactly forty-five minutes to complete your device and have it ready to test. The faster you build your device, the more points you will gain toward your final score. Any unused materials should be returned. The more materials that you return, the higher your final score will be. Therefore, a successful design is one that uses few materials, is easy to build and is able to launch the ping pong ball and hit the target. You will not be allowed to modify the device after the construction period has ended.

Testing:
After everyone has built their Launching Devices, the teams will test their designs. Ping pong balls will be provided. You must set up your device inside the launching base rectangle, as seen in the picture below. You will be granted three chances to get the ball to hit the main target. After each launch you will be allowed to adjust the position of your device within the launching rectangle. Don't worry if you can't get the bull's-eye! There will also be secondary and tertiary targets which are worth fewer points.



The target circles will have rims that are 2in high. The launching pad will have no rim.

Materials List:
On competition day and throughout the design phase, you will be provided with the following materials (61 in total) that can be used in constructing your Launching Device:

10	sheets 8.5x11 inch paper
1	roll of scotch tape
6	straws
4	pencils
1	pen
5	#18 rubber bands
3	#64 rubber bands
4	25mm paperclips
4	50mm paperclips
2	51mm metal prong fasteners
2	¾ inch binder clips
2	1 ¼ inch binder clips
2	12’’ Rulers
4	push pins
2	8oz disposable cups
1	12 inches of string
6	wooden popsicle sticks
2	erasers (approximately 1.75x1x0.5 in)

In addition, your kits will include one pair of scissors and a pencil sharpener.

Rules and Limitations:

1. Your device must be able to self-launch by the use of a trigger. In other words, you cannot be directly responsible for launching the ping pong ball.
2. You device must be reloadable, unless you wish to use only one of your granted chances on competition day.
3. You are not allowed to modify or deform the ping pong ball in anyway.
4. The first contact of the ball with the table will determine the score. For example if the ball hits the tertiary target but then bounces off and goes into the secondary target, we will assume only the tertiary target hit and you will receive points for that target.
5. Your device must fit within the launching pad (12x12 in) and nothing but the ping pong ball can cross the boarders of the launching pad.

Scoring:
There are three objectives to score points in this competition:

1. Successfully launch the ball into the main target
2. Don't use very many materials in your Device
3. Build your Device quickly on competition day

Some objectives are worth more points than others. The full scoring guidelines are given below:

Target Achievement (total of 3 target scores, one for each attempt)

Main Target:	2000 points
Secondary Target:	1000 points
Tertiary Target:	500 points

Materials used:	10*(number of materials returned) points
Construction time:	450 – 10*(construction time, in minutes) points

Total Score = Target Achievement + Materials Used + Construction Time

Prizes:
Prizes will be awarded to the teams as follows:

Grand Champion (highest overall score)
Second Place (second highest overall score)
Third Place (third highest overall score)
Most Innovative Design (get creative!)
Best Self-Releasing Mechanism (easily reloaded and released)
Most Artistic

To make sure that you're eligible to win prizes on the final competition day, make sure that you show up to ***at least five after school sessions and sign in every time***.

Questions:
If you have any questions, please ask your mentor or send an e-mail to David Garland at Dave.Garland@rice.edu or Rachel Jackson at rachel.w.jackson@rice.edu . Enjoy!