THE EFFECTS OF GRAPHING COMPETENCY AND MATHEMATICS COURSEWORK ON KINEMATICS GRAPH INTERPRETATION IN TWO-YEAR COLLEGE STUDENTS

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Abstract

Community college students from a variety of mathematics and physics courses were surveyed in order to examine their ability to extrapolate information from simple unitless linear graphs and linear kinematics graphs. Students enrolled in Algebra I showed little competency in interpretation of kinematics graphs, without regard for graphing ability or previous exposure to physics coursework. However, once students had progressed beyond Algebra I, a positive relationship was observed between graphing ability and kinematics interpretation. This relation became moderately stronger and more consistent at higher levels of math ability, or when considering past experience with physics. Variance remains high, however, suggesting that simple skill in graphing is not sufficient to guarantee understanding in kinematics, regardless of physics background.
Introduction

The objective of this study was to (1) focus on two-year community college students who were unlikely pursue physics as a continued field of study; (2) measure students’ competencies in graphing and kinematics interpretation during the first two weeks of mathematics and physics courses; and (3) determine any significant relationship between unitless linear graphing ability and kinematics interpretation ability in the context of the students’ exposure to past math and physics coursework.

A student’s achievement in college physics is clearly influenced by past experiences in high school level physics courses (Yager & Krajcik, 1989; Sadler & Tai, 2001) and by exposure and skill in mathematics (Fletcher, 1974; Champagne & Klopfer, 1982). Other research has focused on the ability of physics students to understand graphing techniques as a method of presenting data (Beichner, 1994). Much of this research has taken place at large universities, and has focused on physics and engineering students who were likely to continue with formal math coursework above the level of calculus, and with physics above the introductory level (Hudson & Rottmann, 1981). The relation between mathematics ability and physics ability has not been extensively researched for the community college demographic, as much attention is aimed at science majors or four-year programs. This study sought to investigate many of these relations between unitless graphing skill and kinematics skill, though focusing on students at a two-year community college, as well as investigating students with no physics background.

In an attempt to determine the influence of high school physics on success in college physics, Yager and Krajcik (1989) examined two eight-week college physics courses offered to high achieving high school students (B average GPA, A average in high school science). Half of
these students had passed high school physics, while half of them never had a previous physics course. It was found that both groups of students performed equally well in the course, although students without physics experience used tutoring and supplemental help more often. The students stayed in dormitories with their classmates, and had tutors living in the buildings with them as well, giving them a structured, relatively insulated environment. Though they reach an interesting conclusion that high achieving students are not noticeably marred by a lack of high school physics, this demographic is far outside those who typically need to most help in physics: those with below average academic achievement.

An investigation into the influence of previous coursework on college physics scores, Sadler and Tai (2001) sampled students from eighteen colleges and universities for physics and mathematics course history. This study found a positive relationship between high school coursework and the grade earned in college physics. Though it did not focus specifically on graphing and kinematics, it does find an increase in physics performance upon multiple semesters of high school physics and advanced mathematics courses. This result seems consistent with the conclusions reached in the present study.

As a way to evaluate mathematics ability against performance in college physics, Fletcher (1974) has investigated a small number of high school and college students who took a college level introductory physics course. High school students were in Grades 10, 11, and 12, while the college students were typically freshman and sophomores. The high school students who showed a strong grasp of Algebra I and junior high science could perform in a physics course comparably to their college peers. Fletcher’s recommendation to offer physics to the top one-third of students progressing out of Algebra I does not seem far-fetched given that the
present study found relatively strong kinematics achievement among the highest scorers in mathematics.

Relative to the current study, Champagne and Klopfer’s (1982) research into college physics students was structured in a similar style, using preinstructional surveys and questionnaires gathered from a population of college Physics I students. Looking to find a relation between Newtonian physics, math ability, and science experience, they identified a notable positive correlation for the first two of the three. With those two aspects of a student accounting for 34% of their variance, their findings seemed to be in line with this study’s positive correlation between graphing knowledge and kinematics graph interpretation.

Beichner’s (1994) Test of Understanding Graphs in Kinematics, or TUG-K, has many strong similarities to our current investigation, and served as inspiration for this project. Focusing on kinematics graphs and post-instruction testing of high school and college physics students, it examined many of the same topics, such as finding velocity or acceleration of an object from a simple kinematics graph. While the TUG-K featured multiple choice questions and the current study used a survey requiring numeric solutions, the results were comparable. While Beichner reported an average score of 40% from the sampled physics students on the TUG-K, the current study found averages of 37% and 49% from students with either high school physics or college physics backgrounds, respectively.

After giving a precourse diagnostic test on mathematics skills to a sample of introductory physics students, Hudson and Rottman (1981) found a positive correlation between mathematics ability at the start of the semester and final grades in the physics course. The findings give a broader scope to the implications of mathematics ability, but painted with a
wider brush. The current survey investigated graphing as an isolated topic, choosing to focus on one of the common “trouble areas” for math and physics students (McDermott et al., 1981). The current survey, which supports a positive correlation between mathematics and physics ability, applies not just to physics students, but those without physics coursework as well. This seems to suggest that many high achieving students in the Hudson and Rottmann study began their physics course with some baseline understanding of kinematics graphs.

**Methodology and Design**

The study was correlational in style, investigating covariance between success rates for understanding unitless linear graphs and linear kinematics graphs. This relationship was then evaluated in the context of prior mathematics coursework, as well as high school and college level physics coursework. Survey questions were evaluated as either correct or incorrect for the mathematics and physics portions, and recorded via spreadsheet. See Appendix A for the complete survey. The students were also assigned a numeric value on past and present coursework in math and physics. For example, in mathematics a score of zero represented a student only having recently enrolled in Algebra I, while a value of 6 was assigned to a student who had completed a Calculus II course. See Table 1 for the complete listing of this course numbering system.
Table 1

*Mathematics Background Rating System*

<table>
<thead>
<tr>
<th>Mathematics Course Passed</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Algebra</td>
<td>0</td>
</tr>
<tr>
<td>Algebra I</td>
<td>1</td>
</tr>
<tr>
<td>Algebra II</td>
<td>2</td>
</tr>
<tr>
<td>Algebra III</td>
<td>3</td>
</tr>
<tr>
<td>Trigonometry</td>
<td>4</td>
</tr>
<tr>
<td>Calculus I</td>
<td>5</td>
</tr>
<tr>
<td>Calculus II</td>
<td>6</td>
</tr>
</tbody>
</table>

The raw results were organized into seven content areas: unitless intercepts; kinematics intercepts; unitless slope; kinematics slope; ordered pair completion for unitless graphs; ordered pair completion for kinematics; equations for unitless graphs; equations for kinematics; and kinematics theory. Averages for each of these content areas were computed for each demographic, as based on mathematics level and physics level. These content area scores were also aggregated into a success rates for the mathematics (unitless) and physics (kinematics) portions of the survey for each student.

Students' results were then organized into demographics based on a number of criteria: number of successfully completed courses in mathematics, number of semesters of high school physics, and number of completed semesters of physics. These aggregate mathematics and physics content scores for each student were plotted against each other as to readily show any
apparent correlation between graphing knowledge in a mathematics setting and graphing knowledge in a kinematics setting. Linear trendlines were created for each demographic, as well as coefficients of determination for each trendline.

**Assessment and Data Collection**

The survey, which can be found in Appendix A, was given in the first two weeks of the spring semester of 2013. It was given to a sample of Algebra I (n=16), Algebra II (n=24), Algebra III (n=25), Physics I (n=30), and Physics II (n=7) students at Ivy Tech Community College in Lafayette, Indiana. This location was chosen in order to investigate non-physics or engineering majors pursuing two-year associate degrees. The courses were volunteered by the course instructors, and class time was dedicated to taking the survey. Students were informed of the voluntary nature of the survey, its anonymity, and its total independence from any courses the students were enrolled in through Ivy Tech. No information was taken which could identify any individual student.

Students received 20 minutes to answer the 23 total questions, though most did not use the full time allowed. Ten questions were asked of unitless lines, while 13 questions total were asked for the kinematics graphs. Each student also filled out a short questionnaire on their course history in math and physics. Investigated courses were Algebra I, II, and III, Trigonometry, and Calculus I and II. They were also asked about both high school and college levels of Physics I and II, for both algebra and calculus based versions. Students specified either a passing grade, failing grade/withdrawal, never enrolled, or currently enrolled for each course.

The bulk of the assessment was created to test all rudimentary aspects of linear functions. All numbers of interest were either integers or simple ratios, so no calculators were
required (though they were allowed if desired). For each graph, students were asked to identify a number of common features. The values of the X and Y axis intercepts were to be identified, as well as the slope. To test the ability to simply read graphs, they were also asked to determine a value for the dependent variable based on a given independent variable. Finally, in all graphs, they were asked to determine the equation of the line being graphed. These equations were typically reported in the form: \( y = mx + b \).

The first set of questions referred to the graph shown in Figure 1. It is linear and unitless. The X-Intercept is at (-4,0), the Y-Intercept is at (0,2), and it has a slope of \( \frac{1}{2} \). This line is the graphical representation of the equation: \( y = \frac{1}{2}x + 2 \). Students were asked to determine both axis intercepts, the slope, and the equation of the line. To test for the ability to read graphs they were also asked to determine a Y value for a specific value of X. For this problem, while X=6, they were to find a Y value of 5.

**Figure 1.** Unitless linear graph with positive slope and nonzero y-intercept.
The second set of questions was built around Figure 2. Also linear and unitless, its most notable difference from the previous graph is its negative slope. The features students were asked to identify included axis intercepts at (2,0) and (0,3), to find the ordered pair (-2,6) that corresponds to $X=-2$, and find a slope of $-\frac{3}{2}$. Students were also expected to find the equation of the line: $y = -\frac{3}{2}x + 3$.

![Figure 2](image.png)

*Figure 2. Unitless linear graph with negative slope and nonzero y-intercept.*

Figure 3 was the first graph given to the students to feature physics concepts. As a replacement to the previous Y-Intercept problems, they were asked, at a time $t=0$ seconds, to report the object’s location (-3 meters). They were similarly asked to read the graph for $t=3$ seconds in order to find the corresponding position of 6 meters. As a substitute for slope, they were asked for the object’s velocity (3 m/s). They were, as before, asked for the equation of the graph: $D = 3t − 3$. Both $X$ and $T$ (for time) were accepted as independent variables, while
Y, D (for distance) or P (for position) were used as dependent variable. This graph, as well as the Velocity vs Time graph (Figure 4), included a series of physics concept questions that would not be covered in an Algebra 1 course teaching linear graphs. The students were asked to report the object’s acceleration (0 m/s²), as well as when, if ever, the object was moving forward (always) or backward (never).

![Position vs Time Graph](image)

**Figure 3.** Kinematics graph featuring position as a function of time, positive slope, and nonzero y-intercept.

Figure 4 was the final graph presented to the students. They were asked for the Y-intercept as well as to read data off the graph by finding the object’s velocities at t=0 seconds (12 m/s) and at t=10 seconds (7 m/s). As a substitute for slope, the students were asked for the object’s acceleration of $-\frac{1}{2} m/s^2$. As in the previous graphs, an equation was requested for the relationship between time and velocity. Equations given as $v = -\frac{1}{2} t + 12$ or
$y = -\frac{1}{2}x + 12$ were accepted. Finally, as with the graph in Figure 3, they were asked when, if ever, the object was moving forward ($t<24s$) or backward ($t>24s$).

*Figure 4.* Kinematics graph featuring velocity as a function of time, negative slope, and nonzero $y$-intercept.

All surveys were collected and evaluated for accuracy. Inverted ordered pairs of the format $(y,x)$ were scored as incorrect, as well as common misrepresentations of slope (such as $m = -\frac{1}{2}x$ rather than $m = -\frac{1}{2}$ for Figure 4). All correct equations were, by universal student preference, reported in the format: $y = mx + b$, with some variation on variable choice to denote time, displacement, or velocity.
Results

Topic Averages Organized by Mathematics Course History

One of the possible organizations of the survey data was to sort by the highest level of mathematics completed by each student (Figure 5). The Pre-Algebra demographic was surveyed in the opening weeks of an Algebra I course. All other demographics are listed by the highest course completed. Algebra III and Trigonometry have been listed as a single entry, which was done as some of this demographic covered both algebra and trigonometry portions of the material in a single “Pre-Calc” course.

When organized by topic, areas of struggle become clear for each level of development. The ability to determine axis intercepts (Figure 6) clearly improves as experience in math courses increases. Intercepts did prove to be more readily understood by students, with average scores well above the other topics, for all demographics.
Figure 6. Average success rate in finding axis intercepts, organized by highest level of completed mathematics coursework.

The change in unitless intercepts was surprisingly small when comparing the students before and after their Algebra I course. This could be due to previous exposure of graphing material to students just enrolled in Algebra I. Perhaps the confidence in graphing bestowed by an Algebra I course allowed the second cohort to use their knowledge of intercepts on kinematics graphs. This difference cannot be attributed to previous physics instruction, as they both had near identical enrolment in high school physics of approximately 19%, and both had almost no college physics enrollment (2 out of 21 of the Algebra I students, none of the 16 Pre-Algebra students.) This behavior is echoed when investigating the “Reading” portion of the survey (Figure 7.) When asked to report a location or velocity at a specific time, Algebra I students are answering correctly at over four times the rate of Pre-Algebra students, despite a math reading success rate below 20%.
Algebra II students consistently showed higher marks than their Algebra I counterparts on the math portion of the survey (see Figures 8 and 9). Linear topics in Algebra II courses include two equation systems as well as graphing linear inequalities. These topics likely were influential in reinforcing the graphing techniques typically taught in Algebra I. In a surprising turn, Algebra II students scored lower on the physics portion of the exam in every topic except determining slope. What further compounded this odd piece of data was the fact that physics backgrounds actually appeared more consistently in the poorer scoring Algebra II cohort. 13.6% of Algebra II students had completed some form of college level physics, up from the 9.5% reported by the Algebra I students. This is confirmed by the amount of high school physics reported, with 40.9% of Algebra II students having taken physics, up from only 19.0% of the Algebra I group. The authors of this paper have no strong explanations of this behavior, aside from possible statistical error.
The strongest change in scores, for both mathematics and physics portions, for every topic, was when surveying students who had completed an Algebra II course to enroll in physics or Algebra III and students who had completed Algebra III / Trig and continued into physics or higher level math (Figure 9). Though the improved exposure to mathematics course content over the lower cohorts has some effect on these improved scores, there were additional influences to consider. Though high school physics rates drop mildly (38.9% down from 40.9%), the rate of college physics exposure goes up noticeably, from 13.6% up to 22.2% (a 63% increase to college physics rates).

Figure 8. Average ability to identify slope, organized by highest completed mathematics course.
Another influence, one which was not directly addressed in this investigation, was the choice of students to continue in math beyond the general education requirements set by Ivy Tech. Most college programs require the completion of Algebra III for the mathematics portion of general education. Algebra III is so commonly held as a benchmark for general education that it is commonly referred to as “College Math.” As this survey was given in the opening weeks of the semester, students who had completed Algebra II were often enrolled in Algebra III. Though speculation, it is fair to assume many of these students will stop taking mathematics courses upon completion of their required math credit. However, students who had completed Algebra III or Trigonometry chose to enroll either in physics or higher mathematics courses. Though some of these students are pursuing these courses for their own enjoyment, it is likely that many of them are satisfying departmental requirements for physics or higher level math. This fundamentally changes the demographic being sampled. As most of these students were
expected to complete Algebra III, the lowest three cohorts were sample without regard to field of study. However, when focused on a higher level math, we have effectively removed the student body representing fields of study which do not require experience with physics or high levels of mathematics. In turn, we have featured students that are more mathematically inclined, a common trait in those pursuing technical disciplines.

The highest ranked demographic, students who have passed at least one course in calculus, perform as well or better on the physics portions of the survey as the intermediate Algebra 3 and Trigonometry students (Figure 10). However, they routinely scored worse on the mathematics portions relative to the Algebra III / Trig cohort. Though calculus is by definition interested in nonlinear functions, most students of that level have had significant instruction in linear functions, and had every advantage as the Algebra III cohort. This behavior seems to be inverted relative to the Algebra I / II groups. Where Algebra I / II has improving mathematics scores accompanied by poorer physics scores, the Algebra III / Calculus has physics scores that only improve modestly if at all upon reaching calculus, accompanied by a drop in scores for three of the four mathematics sections. With sample sizes for each cohort between 16 and 25 students, it is not a stretch to imagine a sample of above average Algebra III and Trig students, or a sample of below average group of Calculus students.
Figure 10. Average ability to extrapolate information through kinematics graphing, organized by highest completed mathematics course.

The stability of the physics averages between Algebra 3 / Trigonometry and Calculus cohorts may be due to the balancing effects of lower graphing ability and higher exposure to physics course work. While the topics of intercepts, slope, and reading graphs all saw a 15 to 17% drop for the Calculus students, this cohort also had a 44% increase college physics coursework (up to 32% from 22.2%), and had 65% more students with a high school physics background (up to 64% from 38.9%).

**Topic Averages Organized by High School Physics Background**

When organized by high school physics background, we saw near consistent improvement in both mathematics and physics portions of the survey. Though physics likely played a roll, the students with more experience in high school physics also tended to be competent in higher levels of mathematics. While students who had never taken high school physics had, on average, completed Algebra II and not much else (average mathematics level of 2.1, where 2.0 is completion of Algebra II), students with one semester of high school physics had mastered most of Algebra III (mathematics level of 2.8, where 3.0 is completion of Algebra
III). To continue that trend, it should not come as a shock to see large jumps in score when considering students with two semesters of high school physics, as the average student in this sample had completed trigonometry and was learning calculus (an average mathematics level of 4.4 where 4.0 is completion of Trigonometry and 5.0 is completion of Calculus I). As when considering mathematics courses above and beyond general education, common opinion holds that only the brightest of high school students take physics. This perception is not without merit, as high school physics draws upon the top 25% of high school students (National Science Foundation, 1993).

As to the averaged results of these demographics, students who completed either one or two semesters of high school physics found unitless intercepts at approximately the same rate as their counterparts. However, they clearly showed improvement on kinematics intercepts. A single semester of physics resulted in a 37.0% relative growth in kinematics intercepts scores (Figure 11).

![Figure 11. Average success rate in finding axis intercepts, organized by physics coursework taken during high school.](image-url)
A second semester saw 38.4% relative growth above the already improved one semester scores. Upon focusing in retrieving data in kinematics graphs, we saw growths of similar proportions. In this instance, though, reading data from unitless graphs also saw improvement (Figure 12). A single semester of physics let to a 37.0% increase in ability to read data from unitless graphs, while the second semester saw an additional 59.0% growth from the one semester students.

Figure 12. Averages for ordered pair completion, organized by physics coursework taken during high school.

Determining slope saw, coincidentally, identical increases in finding ordered pairs (Figure 13). Both unitless slopes and kinematics slopes grew at identical rates of 37.0%, despite kinematics slope beginning at a much lower success rate than intercepts or completing ordered pairs. Though that consistency confirmed the correlation found while investigating intercepts and ordered pairs, it did nothing to establish causality. An additional semester of physics saw greater amounts of growth in the topic of slope compared to the previous topics, with unitless
slope success rates growing by 58.9% and kinematics slopes by 86.9% compared to the rates for a single semester of physics.

![Slope Average](image)

*Figure 13. Average ability to identify slope, organized by physics coursework taken during high school.*

Determining the equations of lines saw modest improvement for the unitless portion, and a small loss when examining the students who engaged in a single semester of physics (Figure 14). Students which participated in multiple semesters of high school physics, however, saw significant gains over their peers. Scoring over 37% higher than the 6.5% success rate for the one semester students, students who finished a full year in physics answered correctly more than five times as often.
Figure 14. Average ability to determine the equation of a line, organized by high school physics enrollment.

The last topic surveyed, the ability to extrapolate information from kinematics graphs, showed clear improvement with further study in physics (Figure 15). Upon completion of a single semester in high school physics, the score more than doubled, and then nearly doubled again upon completion of a second semester of physics. This trend does not appear to continue when investigating college level physics courses.

Figure 15. Average ability to extrapolate information from kinematics graphs, organized by the amount of physics taken during high school.
Organized by College Physics Experience

A quick glance revealed a noticeable spike in demographic averages upon enrolling in College Physics I. On every topic, in both unitless and kinematics contexts, students who had enrolled in physics consistently outscored their peers (Figure 16).

![Reading Averages](image)

<table>
<thead>
<tr>
<th></th>
<th>No Enroll</th>
<th>Phys I Enroll</th>
<th>Phys I Comp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math Reading</td>
<td>17.02</td>
<td>67.31</td>
<td>59.38</td>
</tr>
<tr>
<td>Physics Reading</td>
<td>27.66</td>
<td>94.23</td>
<td>71.88</td>
</tr>
<tr>
<td>Average</td>
<td>22.34</td>
<td>80.77</td>
<td>65.63</td>
</tr>
</tbody>
</table>

*Figure 16. Average for ordered pair completion, organized by college physics enrollment.*

Though the students who had completed Physics I often did not score as well on the unitless portions as those freshly enrolled in Physics I, they showed solid lasting knowledge of kinematics, especially on the worst scoring topics for the new physics students (Figure 17).
Figure 17. Average ability to determine the equation of a line, organized by college physics enrollment.

Though physics courses have a history of attracting high achieving students, this data cannot be taken at face value, as these students have also had more mathematics experience. While students without any physics history had on average completed only a single course in algebra. The average math score was 1.3, where a score of 1 translated into completion of Algebra I, and a score of 2 translated into completion of Algebra II. Students who had enrolled in Physics I had an average mathematics coursework score of 4.6, which translated to completion of Trigonometry and partial completion of Calculus I. Though some mathematics topics remained high scoring (Figure 18), many showed sharp differences in their results (Figure 19). This disparity in average mathematics coursework had a significant impact when looking at those without any college physics exposure, and precludes us from making strong links between that demographic and any students with college physics experience.
Figure 18. Average ability to identify axis intercepts, organized by college physics enrollment.

Figure 19. Average ability to determine slope, organized by college physics enrollment.

Comparing students who had completed Physics to those freshly enrolled was a more viable comparison (Figure 20), as those who had completed Physics I had an average mathematics history of 4.1, scoring just above completion of Trigonometry. The students who had completed Physics I routinely showed slightly lower scores on the mathematics portion than those beginning a Physics I course. Kinematics scores, however, were comparable throughout.
This presentation of the data sorted the students by the highest course in mathematics completed, but rather than comparing averages, each student’s physics score has been plotted against their mathematics score. This allows us to investigate trends in kinematics comprehension for both high and low achieving students for each course level. Linear trendlines were created, where its slope and intercepts help predict the relationship between graphing knowledge and kinematics knowledge. The slope of our trendline predicts the possible rate of improvement of kinematics knowledge as students become more familiar with basic graphing concepts, while the axis intercept anticipates what the baseline knowledge of kinematics might be for those without strong graphing knowledge.

**Completion of Pre-Algebra**

Students who have only learned or retained Pre-Algebra level content show predictably little experience with kinematics, with an average score of 2.9%. Linear graphing was more familiar, with a 26.3% average score, but still difficult for this group. Graphing, which is
traditionally taught in Algebra I classrooms, was not a skill this cohort was expected to know.

Some students show mild familiarity with the topics, but when a linear trend line is produced for the data set, it shows students with very little adaptation of graphing knowledge to kinematics graphs (Figure 21).

![Graph](image)

**Figure 21.** Total scores in mathematics and physics plotted against each other, for all students who had not completed an Algebra I course.

**Completion of Algebra I**

Having completed Algebra I, this next cohort showed a significant trend towards kinematics knowledge in the higher scoring students. With a demographic average of 35.2% on the mathematics portion, these students did not demonstrate that they had mastered graphing (Figure 22). Students with physics backgrounds (n=4) only scored marginally better than their peers (n=17), with average scores of 37.5%, slightly above the 34.7% average of those with no formal physics coursework. This slight edge was maintained when comparing average kinematics scores of 17.3% for those with physics history, and 15.8% for those without.
Figure 22. Total scores in mathematics and physics plotted against each other, for all students who's highest mathematics course was Algebra I.

Trends amongst individual students, unlike the Pre-Algebra cohort, showed marked increases in kinematics knowledge amongst those most familiar with graphing. Students with no physics course history showed that they could understand kinematics well enough to adapt just under half (41.7%) of their graphing knowledge onto kinematics (Figure 23). With a correlation of $r=0.560$, skill in graphing seemed to have a significant influence on students’ kinematics scores.
Figure 23. Total scores in mathematics and physics plotted against each other, for all students without past physics coursework, who's highest mathematics course was Algebra I.

The few students with any physics history were able to translate their graphing skills to kinematics more readily, with improvement in mathematics relating to a 71% relative increase in kinematics score (Figure 24). Though variance was noticeably smaller than those without physics coursework, we must take this trend with a grain of salt due to the low sample size.

Figure 24. Total scores in mathematics and physics plotted against each other, for all students with any past physics coursework, who's highest mathematics course was Algebra I.
Completion of Algebra II

Students who had completed Algebra II showed none of the trending found in Algebra I students towards knowledge in kinematics relative to graphing ability (Figure 25). Student scores were much more erratic, with many scoring highly on the unitless graphs, while correctly answering very few, if any, of the kinematics questions. The trendline’s correlation is extremely low, so the trendline’s intercept of 9.7% (rather than 1.3% for the Algebra I cohort) is almost deceiving, in a group where 13 of the 22 students could not successfully answer a single kinematics question.

Figure 25. Total scores in mathematics and physics plotted against each other, for all students who’s highest mathematics course was Algebra II.

Contrary to the previous cohort, average scores in the math portion actually fell when comparing the students with and without physics history, from 56.3% (no previous physics coursework) to 43.3% (at least one high school or college physics course) (Figures 26 and 27). Though the students with physics backgrounds on average did slightly better on the kinematics
portion, it was by a thin margin (12.0% improvement from 11.2%). This class did not appear to show notable ties between graphing knowledge and kinematics knowledge.

Figure 26. Total scores in mathematics and physics plotted against each other, for all students without past physics coursework, who's highest mathematics course was Algebra II.

```
Algebra II, No Physics (n=13)

y = 0.0183x + 10.256
R² = 0.0003
```

Figure 27. Total scores in mathematics and physics plotted against each other, for all students with any past physics coursework, who's highest mathematics course was Algebra II.

```
Algebra II, Any Physics (n=9)

y = 0.0564x + 9.5214
R² = 0.0222
```
Completion of Algebra III or Trigonometry

Students who completed at least Algebra III or Trigonometry showed some similarity to the students who had only completed Algebra I. For both cohorts, the trendlines returned modest slopes (49% and 61%) where the more advanced cohort had a slightly stronger correlation between kinematics knowledge and graphing knowledge (Figure 28). They also both projected near zero success in kinematics from students with near zero success in unitless graphing. The scores for this group, however, were more erratic than the Algebra I cohort. The variance is much higher in this group, with $r=.460$.

![Completed Algebra III / Trigonometry](image)

*Figure 28.* Total scores in mathematics and physics plotted against each other, for all students who's highest mathematics course was Algebra III or Trigonometry.

Students who had completed Algebra III or Trigonometry scored higher on average for both measures than either of the lower cohorts. Without a history in physics, students averaged 70% on the unitless portion and 32% on the kinematics portion, higher than every demographic below it by a wide margin (Figure 29). This was seen in the topic by topic analysis,
but it continues to suggest that the student population which continues in math beyond general education is typically stronger on average in both math and physics.

![Graph showing math and physics scores](image)

**Figure 29.** Total scores in mathematics and physics plotted against each other, for all students without past physics coursework, who’s highest mathematics course was Algebra III or Trigonometry.

Those without physics history did not show as strong of relation between performance on the mathematics portion and on the kinematics portion as those with a physics background, and both featured a large variance (Figure 30). The students with physics history scored an average of 90% on the kinematics portion of the survey, and scored an average of 61% on the kinematics portion, nearly double their counterparts without physics. This seems the contradict the lack of trend seen in students who had completed Algebra II, but is more familiar to the behavior seen in students who had taken Algebra I: a strong correlation between the performance in unitless graphing to the ability to decipher kinematics graphs. It is a trend that students with physics backgrounds seem to amplify, though with more variance.
Figure 30. Total scores in mathematics and physics plotted against each other, for all students with any past physics coursework, who’s highest mathematics course was Algebra III or Trigonometry.

**Completion of Calculus I**

Students who reported to have completed Calculus I showed a wide range of skills, including perfect scores on either part of the survey (though never by the same student) and a low score amounting to one correct question out of the entirety of the survey (Figure 31). This spread in knowledge amongst the highest cohort was surprising for a demographic commonly assumed to have a strong working knowledge of the rudiments of mathematics. This could simply be an effect of the low sample size, but there is also the possibility that students falsely reported their history in physics or mathematics. Though the possibility misrepresented student history is pure speculation, one would hope that any calculus student could answer more than one question on the basics of linear graphing.
Figure 31. Total scores in mathematics and physics plotted against each other, for all students who's highest mathematics course was Calculus I or higher.

Though students with no physics history seemed to continue the trend of approximately 50% transmission of graphing skills into kinematics knowledge, the population of this demographic was quite small relative to their peers (Figure 32). Of the students who had completed calculus, only 32% of them had never taken a physics course. Though small, this segment of the student population showed a very similar trend to the Algebra I and the Algebra III / Trig cohorts. All featured small intercepts, with slopes in the 25% to 60% range. This suggested very little understanding of kinematics for those without a strong graphing skillset, but steady improvement in understanding of kinematics for those who simply are better prepared in linear graphing. Though this has been seen in Champagne and Klopfer (1982, see Introduction for discussion,) the behavior was echoed in non-physics/engineering majors in a two-year community college.
Figure 32. Total scores in mathematics and physics plotted against each other, for all students without past physics coursework, who's highest mathematics course was Calculus I or higher.

When investigating the students with some physics background, they showed a strikingly larger intercept than their peers, with at least modest kinematics knowledge shown for even the lowest scoring students (Figure 33). With an average of 73% mathematics score, these physics students averaged lower than their Algebra III / Trig counterparts. Interestingly, though a lower scoring class in mathematics, they averaged a slightly higher kinematics to math ratio than those with a physics background and Algebra III or Trigonometry knowledge.
Figure 33. Total scores in mathematics and physics plotted against each other, for all students with any past physics coursework, who’s highest mathematics course was Calculus I or higher.

Organized by College Physics Background

When no longer filtered by mathematics coursework, the trend found in three of the five mathematics levels between kinematics and unitless graphing does continue to appear. This trend was similar in strength to the relations seen in Algebra I, Algebra III / Trigonometry, and Calculus I cohorts. The Pre-Algebra cohort, which found no significant relation between graphing knowledge and kinematics knowledge, had little effect on the high school and college physics cohorts, as there were only two Pre-Algebra students with any physics background. The Algebra II cohort, which also showed no worthwhile relationship between kinematics and graphing ability, does not seem to have noticeably bucked the overall trend of consistent improvement on kinematics scores relative to higher graphing scores.

Students with no physics background did appear to show near 40% adaptation of their graphing knowledge to kinematics (Figure 34). This suggests that, even with strong graphing knowledge, the average math student could only stretch that ability to cover rudimentary
knowledge of kinematics. The correlation of $r=0.455$ still leaves a strong variance among students caused by uncontrolled influences. These influences on kinematics ability could include skill at solving applied mathematics (story problems), test-taking trends such as test anxiety, or simple lifestyle influences such as health and stress. Those with physics history showed less variance, suggesting that graphing ability has a more significant effect on students with physics knowledge.

*Figure 34.* Total scores in mathematics and physics plotted against each other, for all students without past physics coursework.

The trend presented amongst those without previous physics coursework was amplified when considering students with either high school physics coursework (Figure 35) or college level physics coursework (Figure 36). The rates of improvement in kinematics scores relative to mathematics scores were nearly identical between the high school and college physics demographics. The trendline for both high school physics and non-physics backgrounds predicted very little baseline kinematics knowledge out of their lowest scoring students, but
even the lowest math scores for students with a college physics history were accompanied by
kinematics scores 10 to 12 percentage points higher than their peers from the other two
physics demographics. This jump in kinematics score for those with college physics experience
could be due to the rigor of college level physics courses; or due to the simple fact that college
physics courses happened more recently than a high school course.

Figure 35. Total scores in mathematics and physics plotted against each other, for all students
with high school physics coursework, but no college level physics coursework.
Conclusion

In previous research, positive correlations have been found between course grades in college physics and performance on mathematics surveys, as well as relations between physics grades and previous course history (Hudson & Rottmann, 1981). We have now seen those criteria having a significant effect on students’ ability to understand kinematics graphs. Correlations were relatively strong, suggesting that an increase in a student’s graphing knowledge would yield an improvement in the ability to decipher kinematics graphs. Though we saw averages in both math and physics improve upon completion of math and physics coursework, there were a large number of students in every demographic who performed poorly on both sections of the survey. This suggests that mathematics entrance requirements for physics courses may not be enough to ensure the foundational knowledge that college
physics requires, as at all levels, some students have grievous errors in graphing knowledge that clearly influences their capacity to understand kinematics graphs.

Though averages for each topic typically improved mildly as higher level mathematics courses were considered, an exception was a large spike at Algebra III / Trigonometry. Students were surveyed in the first two weeks of math and physics courses, which means that if they had completed Algebra III previously, they had made one of two choices. Either they continued on in mathematics beyond their general education requirement, or they had chosen to enroll in a physics course. Regardless of which route led the student to this survey, it has featured students who are statistically more skilled in mathematics (Sadler & Tai, 2001).

Calculus students showed a small drop relative to the Algebra III / Trigonometry cohort. Perhaps linear graphing simply had not been recently thought about by the relatively small sample. Perhaps with a larger sample size, downticks in performance from the Algebra II demographic and the Calculus demographic could be investigated further. The Algebra II cohort also showed surprising behavior, which may or may not be explained by the small sample size. The Algebra II cohort showed almost no relation between kinematics knowledge and graphing knowledge. This may have been an effect of the placement tests in Ivy Tech, or perhaps just an anomalous group of students, but few possible causes presented themselves to explain this behavior.

One of the most surprising things found did not, in fact, come from the processed data, but through unsolicited commentary by the students. The most noteworthy survey came from a student who had claimed to have passed Calculus 1, passed two semesters of high school physics, and either withdrew or failed a college level physics course. This student scored a 20%
on the math portion, 15% on the kinematics portions, and added some colorful commentary including “I hate you for these graphs,” and “You are quite possibly Satan.” Though this student’s unsolicited commentary was not the only message found amongst the surveys, it seems surprising that someone who has passed Calculus I would have such a difficult time with linear graphs, and would feel so strongly about the challenge. Perhaps the student was not honest about their course history, or perhaps they had simply always had trouble with graphing. Either way, it would not be surprising to find more than one student like this in a larger sample, though hopefully in smaller proportion. Perhaps in future studies of this style, opinions could be solicited to give a picture of not just student skills, but of preference and confidence as well.

It seems like a continuation of this study would involve more sampling after a revision to the survey. The survey could stand to be adjusted for clarity, and the kinematics theory questions may not necessary. Though they provided some more difficult physics questions to raise the upper extreme on kinematics knowledge, only three students received a perfect score on the kinematics portion. This has the added side effect of making the kinematics portion tougher, by adding often missed questions without a suitable analogue in the mathematics portion. A proper unitless analogue could be developed, or the five kinematics knowledge questions could be revised or omitted to create a more symmetric survey. Recording course history could be streamlined as well to avoid careless mistakes. As the students were requested to record course history in code (P for Pass, X for Withdrawal / Fail, etc.) many did not hold to this code when filling out the surveys. The most common errors involved recording Withdrawal / Failure for every class the student did not pass, even if they never took the
course, or reporting themselves as currently enrolled in every course they’ve ever taken, rather than reporting they passed. A possible replacement method could involve student choosing between four listed options for each course: currently enrolled, pass, fail / withdrawal, never taken. This would help ensure a more error free recording of course history for each student.

The sample size never went above 25 for any single level of math coursework. That has certainly not given strength to the prospect of this behavior existing in the larger community. By increasing sample size and spreading the study out over multiple semesters, the study would help control for the influence of any single teacher, student body that is far above or below average skill, or a number of other external affects. It could also allow for a more reliable measure of the frequency of high and low achieving students at any given math or physics level, a statistic with limited value due to the small sample size of this survey.

Despite these issues, a strong positive correlation was found between mathematics and kinematics skills, accompanied with an increase in overall score with each successive math course. Though every course level had low scoring students, the highest achievers were able to routinely decipher more than half of the kinematics portion without any previous physics course work, provided they had completed Algebra III. The results seem to suggest that any group of students a physics instructor might receive would contain some students with little knowledge of graphing or kinematics, a universal finding of this survey. However, those most well versed in unitless graphing seemed poised to pick up kinematics graphs with relative ease, likely understanding many core concepts before the first minute of instruction.
References


Appendix A

The Survey

GRAPHING COMPREHENSION IN MATHEMATICS AND PHYSICS

DATE:___________________

COURSE:___________________

Thank you for taking this survey. It is totally voluntary, confidential, and in no way impacts your progress in the course you are currently enrolled in.

Please fill in a check mark “✔” for any classes which you are currently enrolled in. Place a “P” in any classes you have previously passed. Place an “X” in any classes in which you either withdrew or did not pass. If you have not taken a class, leave the space blank.

MATHEMATICS

___ Algebra I
___ Algebra II
___ Algebra III
___ Trigonometry
___ Calculus I
___ Calculus II

HIGH SCHOOL PHYSICS

___ Algebra based Physics I
___ Algebra based Physics II
___ Calculus based Physics I
___ Calculus based Physics II

COLLEGE PHYSICS

___ Algebra based Physics I
___ Algebra based Physics II
___ Calculus based Physics I
___ Calculus based Physics II
1. What is the X-Intercept?

2. What is the Y-Intercept?

3. What is the Slope of the line?

4. When X=6, Y=?

5. What is the equation of the line?
6. What is the X-Intercept?

7. What is the Y-Intercept?

8. What is the Slope of the line?

9. When X=-2, Y=?

10. What is the equation of the line?
11. What is the object’s location at \( t = 0 \) seconds?

12. What is the object’s location at \( t = 3 \) seconds?

13. What is the object’s velocity?

14. What is the object’s acceleration?

15. When, if ever, is the object moving forwards?

16. When, if ever, is the object moving backwards?

17. What is the equation that defines the object’s position as a function of time?
18. What is the object’s velocity at t=0 seconds?

19. What is the object’s velocity at t=10 seconds?

20. What is the object’s acceleration?

21. When, if ever, is the object moving forward?

22. When, if ever, is the object moving backwards?

23. What is the equation that defines the object’s velocity as a function of time?