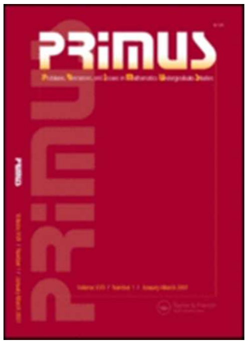

CoOrdinated Math-Physics Assessment As An Alternative Pathway in Early STEM

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CoOrdinated Math-Physics Assessment As An Alternative Pathway in Early STEM[1]

CoOrdinated Math-Physics Assessment As An Alternative Pathway in Early STEM^2

Abstract: Improving student success in introductory calculus and physics courses is critically important for our students' path in STEM fields. Many students who have an intuitive physics knowledge fail calculus and are pushed to delay or drop their majors in technical fields. One way of addressing this issue is by following a program that is designed to identify their specific needs and maximize their potentials in STEM fields. At University One, a specific calculus section, COMPASS: CoOrdinated Math-Physics Assessment for Student Success, is designed to prepares students by introducing mathematical concepts with physical applications. The implementation of the COMPASS program at University One for academic year 2015–2016 and year 2016–2017 is described in this paper. This includes basic information on pre-tests and students identification tools, some example lectures, and reports on analysis of students' performance and assessment for two academic years. Through practices of two years of COMPASS program, University One recognizes students paths in STEM education need to be specified by their backgrounds and subjects of interests. This will help to improve their success in their college education.

Keywords: Student Success, STEM, Calculus, Physics, COMPASS

1 INTRODUCTION

National trends for the number of students in STEM disciplines predict continued declines [12]. These concerns are echoed in the recent president's council of advisors on science and technology reports [17]. This report is used to identify strategic targets for educational innovations at the undergraduate levels. Specific projections point to a need of an additional one million Science, Technology, Engineering and Math (STEM) graduates with specific recommendations to provide support for replacing standard laboratory courses with discovery-based research courses and to diversify pathways to STEM careers.

Note that student retention in STEM disciplines requires an institutional wide commitment. A wider commitment by the institution can foster an environment where students have more options that allow them to choose a program that better matches their needs. The effort for the activities described in this paper focus on the first year calculus and physics curriculum. Our goals are to retain more incoming STEM students in STEM disciplines by identifying specific needs as early as possible, improve student achievement in introductory STEM courses, and develop a replicable model in a research-based educational environment. The activities experienced in these learning venues are designed to take advantages of the students' relative strengths.

To address these concerns University One adopted a number of changes to the introductory calculus and physics courses. The goal is to immediately identify and support student needs as early as possible [1, 2, 3, 4, 5, 6]. University One is also developing multiple programs to support students based on their specific needs. An overview of the broader context at University One is presented below.

The core fundamental courses at University One are introductory calculus I&II and physics I&II. The proportions of students enrolled in our core fundamental courses are approximately 75% engineering, 8% business (typically from our Interdisciplinary Engineering and Management curriculum), 14% math and science, and 3% undecided majors. Each student has a relative strength or weakness in physics concepts (identified as P+ or P-), and each student has a relative strength or weakness in math skills (identified as M+ or M-). Correlations between math and physics performance (problem solving) are well documented in the educational research literature [11, 7]. University One initiated a comprehensive assessment of first-year performance in the introductory calculus and physics courses made possible by a 2009 grant from Proctor & Gamble (P&G) [13]. This grant funded an assessment of students' performance in first-year physics and calculus courses, with the goal of understanding how better to retain students in STEM programs. The study led to two specific programs associated with high and low risk categories described below [14, 15].

In an effort to improve student performance and retention for STEM majors, University One adopted a strategic plan to identify under-prepared or "high risk" students using mathematics and physics diagnostic surveys. In the last two years approximately 25% of the STEM majors entering University One were recommended to take an alternate schedule of first semester courses so that they could develop stronger math skills prior to attempting a calculus-based physics course. As a result of this initiative, the mean of the first semester chemistry grade of the "high risk" group increased by half a letter grade beyond the previous 5-year average, and the average of the first physics grade (second semester result) increased similarly.

An additional program has been in place for students with the highest levels of preparation through the P&G grant [13]. University's "Physics Team Design Program" provides "low risk" students with a challenging real-world laboratory design experiences within the first year introductory physics courses. The program is open to all majors and replaces the traditional physics laboratory requirements with advanced group projects. These students take part in a semester-long "research simulation experience" in which they analyze all aspects of a vehicle dynamics problem, including experimental design, mathematical modeling, and numerical prediction.

The large majority of students are in a "medium risk" category. The students in the medium risk category have a relative strength in one category and a relative weakness in the other category. The goal is to motivate the development of the other, weaker category by making use of theses students' relative strength in the opposing area. Past assessments indicate that the students who have a relative strength in physics concepts and a relative weakness in math skills, the students in the (P+,M-) category, have lower retention rates compared to their (P-,M+) colleagues. Part of the "medium risk" group is the focus of this paper. Those students are selected to take part in the specific program designed for them, CoOrdinated Math-Physics Assessment for Student Success (COMPASS). A discussion on how the students are classified is given in Section 2. It also includes the adaptations adopted to the introductory calculus and physics courses at University One. Calculus and physics are two core STEM courses, which are closely coordinated in the COMPASS program. The COMPASS program takes advantage of the students' greater understanding of physics concepts to motivate important ideas and topics in calculus. This is the motivation in designing the COMPASS program. A few lecture examples are provided in Section 2, as well as analyses on data collected during academic years 2015 and 2016 are given in Section 3. Section 4 draws some conclusions on the successes and challenges of the program and discussions on future work of the COMPASS program.

2 The COMPASS Program

As described in previous section, University One has established programs to address the needs of students facing more challenges as well the students with the highest levels of preparation. The part of the remaining groups of students are addressed in a new program, COMPASS. The goal of the COMPASS program is to identify student needs prior to enrollment and then direct them into a program that can best meet their needs. The identification step is done by measuring their understanding of fundamental physics concepts and also their basic mathematical skills. The discussion here is focused on the large majority of students who are in a "medium risk" category. As mentioned earlier, past assessments indicate the students in the (P+,M-) category, have lower retention rates compared to their (P-,M+) colleagues. Thus, the (P+,M-) students are the targets of the COMPASS program.

2.1 Student Identification

To measure the students' understanding of physics concepts the Force Concept Inventory (FCI) [8, 10] was used. The FCI is a multiple-choice test designed to assess students' Newtonian and non-Newtonian conceptions of force [9]. For example, the first question on fall semester 2015 test is *Two metal balls are the same size, but one weighs twice as much as the other. The balls are dropped from the roof of a single story building at the same instant of time. The time it takes for the balls to reach the ground below will be (Select one):*

a. about half as long for the heavier ball as for the lighter one.
b. about half as long for the lighter ball as for the heavier one.
c. about the same for both balls.
d. considerably less for the heavier ball, but not necessarily half as long.
e. considerably less for the lighter ball, but not necessarily half as long.

First, it is important to recognize that the FCI was not envisioned to be used as a diagnostic tool. It was designed to be used as part of a pre- and post-test system to measure student gains with respect to their understanding of fundamental concepts in mechanics. Total points for the physics survey is 30. The cutoffs for physics survey precisely categorized students into three group: P-, P-+ and P+ when combined with the mathematics readiness test.

The mathematics readiness test (math survey) designed by University One is used to measure students' basic mathematics skills [1]. This test focuses on the fundamental material from pre-calculus, including 35% algebra, 25% trigonometry, 20% exponents and logarithms, and 20% geometry. The use of the FCI runs counter to the original intent of the measurement, but when combined with math pre-test identification for the COMPASS program students' needs can be more effectively addressed. The cutoffs for math survey categorized students into two groups: M- and M+.

A key question of the assessment is how to determine appropriate measures to increase the power of the predictive measurements. Currently the cutoffs have been determined through trial and error, as shown in Table 1. A future goal is to identify more effective ways to modify and adapt the cutoff points. Note that the total points for the math survey is 20.

The historical data at University One is shown on the left of the Figure 1 for years 2008–2014 and on the right for year 2015. The left plot provides a sunflower plot (used for large data sets) [16] of six years (2008–2014) of the combined math/physics pre-test data for incoming University students who were enrolled in both calculus I

Table 1. Current cutoff values to determine a student's math survey scores.

M-	Math Survey < 13
M+	Math Survey ≥ 13
P-	Physics Survey < 15
P-+	Physics Survey$/30 < 0.9 - (0.4/0.65) * ($Math Survey$/20)$
P+	Physics Survey$/30 \geq 0.9 - (0.4/0.65) * ($Math Survey$/20)$

Table 2. Mean grades for students in each of the four categorizations from 2008–2014.

Category	Rick	Mean Math	Mean Physics
(M-, P-)	High	.69	.63
(M-, P+)	Medium	.74	.73
(M+, P-)	Medium	.80	.73
(M+, P+)	Low	.85	.82

and physics I, where the number of lines associated with the data represents the number of students who received that score. For example, × is standing for the case where four students received that score. This plot includes only the overlap students for which matched math/physics pre-test data were available. The scatter in the data speaks to the diversity of incoming student preparation levels, which is the challenge that instructors face in addressing the varying levels of needs, and the importance of innovative and strategically targeted curriculum development efforts. The Pearson correlation coefficient is 0.23 which indicates little correlation between the two scores and confirming that we have identified two relatively independent measures. The physics pre-test measures only initial conceptual understanding and does not measure mathematical skills. The low correlation is useful in identifying the four distinct regions or groups of students with different levels of initial preparedness. It provides a unique starting point for tracking subsequent math/physics correlations in problem solving.

The mean of the diagnostic scores for students in each of the four categorizations from year 2008 to 2014 are shown in Table 2. The (M-,P+) group (initially well prepared in physics and less so in mathematics) had average scaled grades of 0.74 in math and 0.73 in physics. These average scores are not extremely low, although they are lower in comparison with a mean of 0.80 in math for (M+, P-) group and 0.85 in math for (M+, P+) group. The mean performance of this group indicates that students testing lower on math skills struggle in both introductory courses despite their strong conceptual base in physics.

The COMPASS program is first launched at University One during fall semester in 2015 for calculus I/physics I, and students who completed both courses will go on second semester of the COMPASS program for calculus II/physics II during spring semester in 2016. Thus, the students' survey scores for year 2015 are presented separately from other years in Figure 1. The scatter plot shows the scaled survey scores for the incoming class for the fall semester in 2015. A math cutoff of 0.675 and a physics cutoff of 0.50 are used. The math cutoff is chosen as a minimal competency requirement and has been used for the previous six years. The physics cutoff has also been chosen as a minimal competency requirement and is close to the six-year physics pre-test average of 0.52. The same cutoffs are used for academic year 2016–2017.

The numbers of students in the (M-,P+) are not as sensitive to the cutoff values as the other groups. As an example, Table 3 provides the numbers of students in each category if the cutoff values are 0.45 in physics

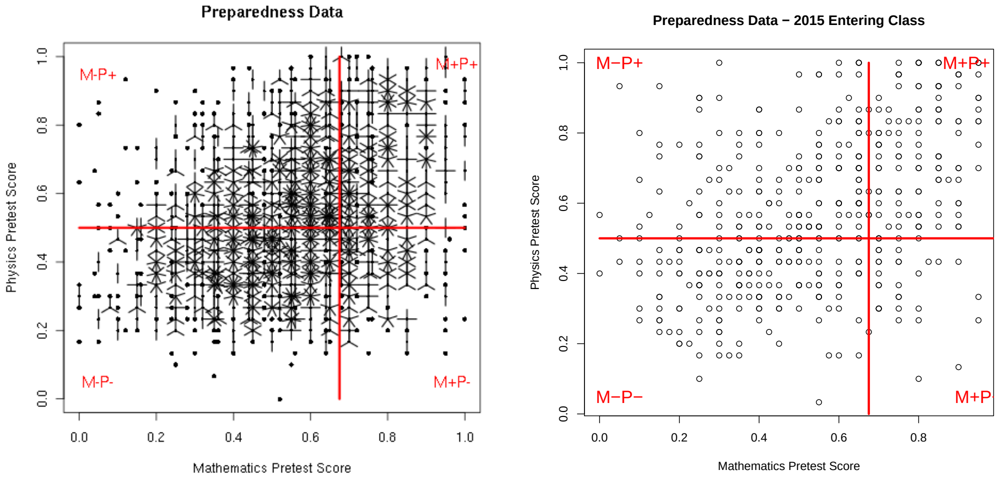

Figure 1. Each student's scaled physics survey score with respect to the their scaled math survey score for years 2008–2014 on the left and for year 2015 on the right. The data points are marked with symbols, where the number of lines associated with the data point represents the number of students who received that score. For example, ✕ is standing for the case where four students received that score.

and 0.625 in math, decreased by five percent, and increased by five percent. In all three cases the numbers of students in the (M-,P+) group show a little change. The numbers of students in the (M-,P-) and the (M+,P+) groups, though, show a great deal of change and appear to be sensitive to the values specified for the cutoffs. The sensitivity analysis of the cutoffs indicated that cutoffs in the range of 0.4-0.5 for the FCI and 0.575-0.675 for the basic mathematical survey result in acceptable changes in the numbers of students designated for the medium risk category.

The efforts of the COMPASS program are to better support the (M-,P+) students. The curriculum of the COMPASS leverages their physical intuition as a way to motivate the development and enhancement of their mathematics skills.

Table 3. Exploration of the sensitivity of the cutoff values. The numbers and percents of students in each of the four categorizations during fall semester in 2015 are given with respect to cutoffs 0.5/0.45/0.4 in physics and 0.675/0.625/0.575 in math.

Cutoff values P/M	P0.5/M0.675	
Phys/Math	M-	M+
P-	124 (26.78%)	33 (7.12%)
P+	153 (33.05%)	153 (33.05%)
Cutoff values P/M	P0.45/M0.625	
P-	172 (37.15%)	34 (7.34%)
P+	146 (32.53%)	111 (24.97%)
Cutoff values	P0.4/M0.575	
P-	206 (44.49%)	28 (6.05%)
P+	145 (31.32%)	84 (18.14%)

2.2 COMPASS Calculus Curriculum

Once the students in the (M-,P+) group are identified the next question is how to address their needs and support their efforts. The approach is to make use of active learning strategies that build on their physics intuition with the goal of raising their understanding of the mathematical concepts to the levels of their peers.

The COMPASS program tries to provide multiple modes in the classroom with short mini-lectures that support the use of highly scaffolded classroom activities. Students meet with their calculus professors three times a week and 50 minutes each time. During the class meeting time, a set of activities is provided that requires individual thinking and establishing ideas of calculus in physical situations. This process requires more reasoning, justification, and explanation. There is also an additional recitation where students meet with an undergraduate teaching assistant. During this time the students take parts in practice sessions to help raise their basic skills and to reinforce the exploration that takes place in the regular meeting times.

In addition to the class meetings, the program emphasizes on open-ended projects that require extensive writing in cooperative groups. In a recent semester the first project required students to design a roller coaster. The students were required to use their knowledge of analytic geometry and calculus (along with some provided information from physics) to solve some basic roller coaster layout design problems. The design requirement is that the ride should be 45 meters high, starting with a linear descent of slope $m = -1.2$ followed by a circular reversal into a parabolic section of track that would give the sensation of zero gravity, with the launch angle of 60 degrees. In this project, the following concepts are assessed: (1) slope of tangent lines; (2) equation of a parabola; (3) trig functions; and (4) derivatives of all functions involved. The student teams made use of Newton's laws to construct a mathematical model, analyze the model, and then make predictions about the performance of their design.

2.3 Lecture Example: Design Train Track using Integration by Parts

All the calculus students at University One were given the same final exam, but the homework, monthly-exams are different, which are instructor-relevant. The COMPASS students did some of the problems like one discussed below but no more than half of the lectures. This example lecture requires students to analyze a model railroad system during their second semester. The students are presented with a model railway track-circuit signaling system. Train wheels and axles provide an electrical connection between the two rails on which they travel. This enables a track signaling circuit to detect the presence of a train on a given section of track. The detailed COMPASS physics lab in provided in the Appendix.

The first step is to derive a mathematical model for the system which is accomplished using Kirchoff's loop rules. Then students will proceed through the steps in order to develop their own models of the system. First, let $q(t)$ be the electrical charge at time t, then total charge stored in the capacitor in an RC circuit is governed by

$$R * I(t) + \frac{1}{C}q(t) = V(t), \tag{1}$$

where R is resistance of the train which is a constant parameter, C is the capacitance of the train which also is a constant parameter, and $V(t)$ is the voltage drop as a function of time associated with the train. The current is the rate of change of the charge within the train, i.e., $I(t) = q'(t)$. Thus,

$$Rq'(t) + \frac{1}{C}q(t) = V(t), \tag{2}$$

$$CRq'(t) + q(t) = CV(t). \tag{3}$$

The next step is to determine the equation of motion for the train. Assume that the speed of the train at any time is $v(t)$, which is governed by

$$\tau v'(t) + v = mV(t), \tag{4}$$

where $RC = \tau, m = c$. This equation is obtained by assuming the speed of the train is proportional to the electrical charge. In this instance the students will determine the values of the parameters through experiments in the COMPASS physics lab. Suppose that $\tau = 2, b = 1, m = 2$. The previous equation can be simplified to

$$v'(t) + \frac{1}{2}v(t) = V(t). \tag{5}$$

This is a first order differential equation. A trivial solution, $v(t) \equiv 0$, can be found easily if $V(t) \equiv 0$. Note that this is not a separable equation, and it represents a new challenge for our students. Within the COMPASS curriculum, students examine the cases where $V(t)$ is linear. The trick in equation (5) is to take advantage of the product rule to find an integrating factor. The students are expected to multiply the equation by a clever choice of a function, $f(t)$, to get

$$v'(t)f(t) + \frac{1}{2}v(t)f(t) = V(t)f(t). \tag{6}$$

The leap for the students is to recognize that this becomes the product rule when

$$f'(t) = \frac{1}{2}f(t). \tag{7}$$

The last step in this process from the perspective of mathematics is to extend the idea and recognize the role of the product rule. The left hand side of the equation becomes a total derivative. A further exploration of the product rule motivates another way to use this tool and leads to a derivation of integration by parts. Thus, equation (5) becomes that

$$(v(t)f(t))' = V(t)f(t), \tag{8}$$

$$v(t)f(t) = \int V(t)f(t)dt. \tag{9}$$

Notice that equation (7) is introduced in calculus I where the solution is $f(t) = e^{t/2}$. Thus,

$$v(t) = e^{-t/2}\int V(t)e^{t/2}dt. \tag{10}$$

COMPASS students practice the integration by parts for cases where $V(t)$ is constant function, linear function, quadratic function, and periodic sine or cosine functions.

3 Analysis on Students Performance

Since the COMPASS program was first launched in 2015 and runs again in 2016. Currently, the third group of the students in 2017 COMPASS program. There were 18 students successfully completed COMPASS program through academic year 2015, and 24 students in 2016. Data on students performance and analysis on the data are presented in this section. As described in previous sections, the cutoffs used in both years are 0.45 in physics and 0.625 in math. The following categorizations are used in the discussions.

Group 1 (COMPASS)	students in (M-, P+) group and enrolled in COMPASS program during academic years 2015 and 2016
Group 2 (Eligible)	students in (M-, P+) group and not enrolled in COMPASS program during academic years 2015 and 2016
Group 3 (Others, ALL)	students who are not in COMPASS program during academic years 2015 and 2016

The numbers of students in all groups during fall semester 2015 through spring semester 2017 are given in Table 4.

Table 4. Number of students in each of the three groups.

	Fall 2015	Spring 2016	Fall 2016	Spring 2017
Group 1	25	18	27	24
Group 2	146	128	89	78
Group 3	492	420	456	365

3.1 Students Performances on the Common Final Exam

Now some preliminary results on students performance on their calculus and physics courses are given by groups. Students who take calculus courses at University One take a common final exam. Each question on the final exam is graded twice by two graduate teaching assistants. Thus, the grades on final exam are a good indicator on students performance after taking the course. The final calculus exam scores are listed in Table 5 by groups.

The average final exam grades of the COMPASS students are higher than other groups. In addition, the COMPASS students performs extremely well on their calculus II final exam (average 75.82) compared to average of 69.60 for group 2 and 69.26 for group 3. The difference in the exam scores for group 1 and group 2 in the fall semester 2015 is negligible. However, the difference is wider for the second semester. An independent t-test to compare the two groups provides a p-value of 0.06. However, [18] indicates that p-value is not the final arbiter of significance if effect size is big. Historically this group of students have struggled in their calculus-based, introductory physics courses, and their relative weakness in mathematics is a difficult obstacle with respect to their overall academic success. However, the data shown above indicates that the COMPASS students are at the similar level as other students. This is a significant improvement, despite the historical record of the students.

In addition, students' understanding of basic calculus concepts is explored. One example of this is a common physics related calculus conceptional question that was included on the common final exam. This question focuses on the mean value theorem and requires students to translate it into a physical context. The question states:

A car starts from rest at a stop light. At the end of 10 seconds, its position is 100 meters beyond the light. Three statements are given below. For each statement indicate if it must be true, must be false, or if it is not possible to determine indicate that you cannot tell from the given information. For each statement provide a

Table 5. Comparison between three groups on their average final exam grades during fall semester 2015 and spring semester 2016, where is the full credit is 100.

MA131	Average	Standard Deviation
Group 1	77.63	10.89
Group 2	76.52	17.52
Group 3	73.42	16.80
MA132	Average	Standard Deviation
Group 1	75.82	9.95
Group 2	69.60	16.44
Group 3	69.26	17.54

complete, one sentence explanation for your reasoning.

(a) *[3 pts] True / False / Cannot Tell. Its final speed is 10 meters per second*

(b) *[4 pts] True / False / Cannot Tell. At one or more points in time its speed was 10 meters per second.*

(c) *[3 pts] True / False / Cannot Tell. It did not move faster than 10 meters per second at any time.*

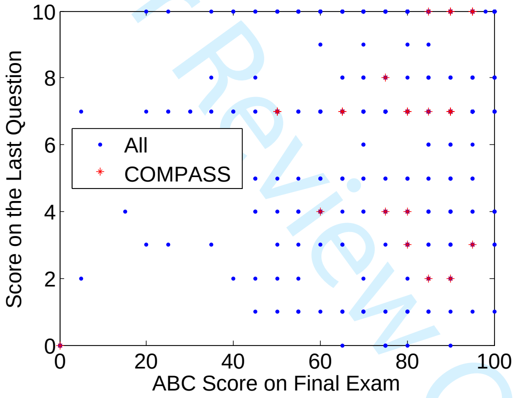

Figure 2. The students' scores on the last question of the final exam versus their ABC score at the end of the semester during fall semeser in 2015.

Figure 2 shows a comparison of the student scores on this question in relation to their score on our common gateway exams. The common gateway tests (ABC) represent a minimum competency test of basic ideas in the course, and it is part of the final exam. This is very much similar to the math survey the students took before the group categorization. The COMPASS students tended to demonstrate a high level of mastery on question, but on average the other students failed to receive half of the credits.

3.2 Analysis on Students' Failing Rate and GPAs

A direct comparison on students' final course grade distributions for calculus I & II and physics I & II between all three groups are given in Figure 3 and Figure 4. For simplicity, course numbers instead of course names are used in the results, in which MA131 stands for calculus I, MA132 stands for calculus II, PH131 stands for physics I and PH132 stands for physics II. The COMPASS students in physics courses tend to stay in the middle of the

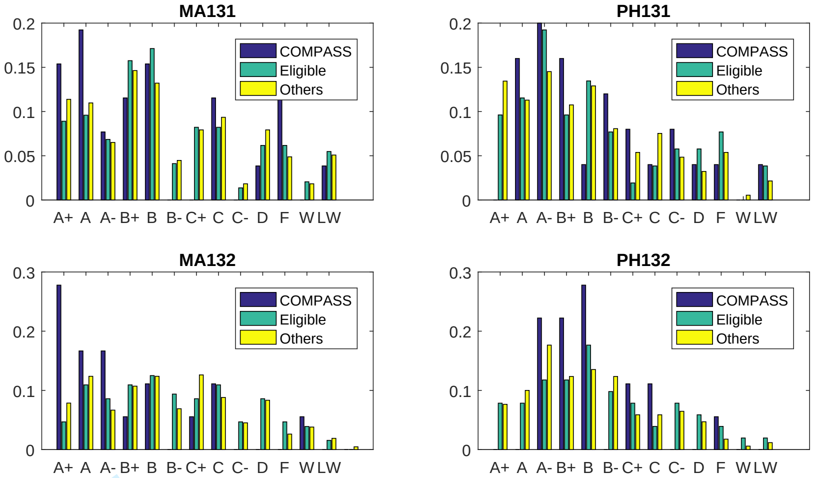

Figure 3. Comparison of students course performance for MA131, MA132, PH131, and PH132 during year 2015–2016, where I stands for incomplete, W stands for withdraw and LW stands for late withdraw.

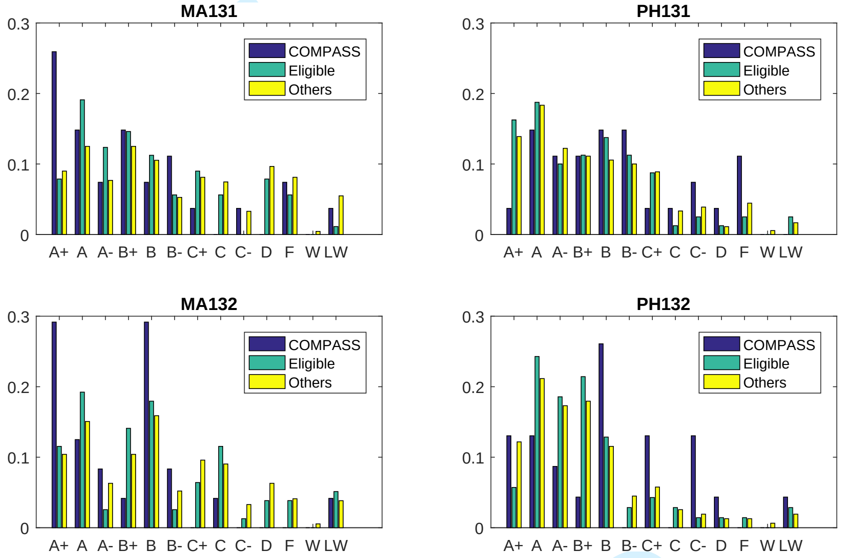

Figure 4. Comparison of students course performance for MA131, MA132, PH131, and PH132 during year 2016–2017, where I stands for incomplete, W stands for withdraw and LW stands for late withdraw.

grade distribution, while their calculus performance tend toward the high end of the grade distribution during all semesters. Possible reasons include (1) the instructor in different sections tend to have different grading standards; and (2) the COMPASS group is relatively small compared to other groups.

Comparison on students' failing rates between three groups for MA131, MA132, PH131 and PH132 is presented in Table 6. All students' course grades can be A+ through F, in addition to incomplete (I), withdraw (W) and late withdraw (LW). Students who received grades D and lower including I, W and LW are denoted by $\leq D$, and students who received grades F, I, W, and LW are denoted by $\leq F$. The reason that grade D is included as part of the failing criteria is that at University One, students are recommended to retake calculus if their course grades was D or lower. There are less students who fail the courses in COMPASS group when considering students' grades are D or lower. This implies that the COMPASS program provides more opportunities for students to stay on track of their academic program. For grades that are F or below, there is no significant difference between COMPASS group and all others in their performance in physics courses.

One reason may be because of the COMPASS students are randomly placed in one of the three big lectures for physics. The students in COMPASS group are selected due to their low performance in math survey and better physics intuition. However, the physics classes offered at University One are calculus bases physics. Thus, with weaker math skills, students in COMPASS program did not fall behind in their physics or calculus classes. Thus, the COMPASS program helped students to improve their performance in general.

Table 6. Comparison of failing rates in percentages (%) between three groups for MA131, PH131, MA132 and PH132.

	Year	2015–2016			2016–2017		
	Group	1	2	3	1	2	3
MA131	$\leq D$	*16*	20	20	11	15	24
	$\leq F$	*12*	14	*12*	11	*7*	14
PH131	$\leq D$	12	17	*11*	15	*6*	8
	$\leq F$	*8*	12	*8*	11	*5*	7
MA132	$\leq D$	*6*	19	17	*4*	13	15
	$\leq F$	*6*	10	8	*4*	9	8
PH132	$\leq D$	*6*	14	8	9	6	*5*
	$\leq F$	6	8	*4*	*4*	*4*	*4*

Examination of the students grades in relation to other measures used to predict their performance is described as follows. The comparison between three group's students on their SAT math score, University One math survey, high school GPA, and University One cumulative GPA after their freshman year is shown in Table 7 and Table 8. Although there is no significant difference between three groups on the average on the University One cumulative GPA, the COMPASS students have a higher median compared to other groups, where median is the midpoint of the grades' frequency distribution. This means that the COMPASS students tend to differ from catching up with the good students, or completely fall behind.

Table 7. Comparison between three groups on their average surveys 2015–2016 cohort.

Average	SAT Math	Math Survey	HS GPA	Univ. GPA
Group 1	597	10	3.657	2.870
Group 2	544	8	3.540	2.872
Group 3	550	10	3.545	2.919
Medium	SAT Math	Math Survey	HS GPA	Univ. GPA
Group 1	620	11	3.676	3.123
Group 2	610	9	3.648	3.000
Group 3	610	10	3.695	2.966

Table 8. Comparison between three groups on their average surveys for 2016–2017 cohort.

Average	SAT Math	Math Survey	HS GPA	Spring CUM GPA
Group 1	630	12	3.584	2.972
Group 2	643	13	3.648	3.150
Group 3	614	13	3.642	2.941
Median	SAT Math	Math Survey	HS GPA	Spring CUM GPA
Group 1	630	12	3.630	3.030
Group 2	640	13	3.710	3.345
Group 3	610	13	3.715	3.101

4 Program Success and Challenges

The COMPASS (CoOrdinated Math-Physics Assessment for Student Success) program is one-year long program that is designed to fit students who have relatively weak math skills but relatively stronger physics intuition prior college. The program uses the Force Concept Inventory (FCI) and a math pre-test survey designed by University One to identify students by their performance on the surveys. The program focuses on enhancing the academic success of one group, the (M-,P+) students. The COMPASS students at University One take calculus I and physics I during the fall semester, and who completed both courses can remain for the spring semester COMPASS program which requires students to take Calculus II and Physics II at the same time. The program reorders calculus topics to remain consistent with the order of topics in the physics curriculum. In this way, each mathematical topic is given a context and a meaning by explicit connections between the two courses. These are reinforced in the discussion class with undergraduate teaching assistant in calculus classes and laboratory sections in physics classes. Through two years of practices of COMPASS, we found that the students can be benefited from a coordinated calculus-physics courses throughout their first year of college experience, especially whose who have had relatively weak foundations in their pre-calculus skills with good physics intuitions.

Additionally, there are some challenges: (1) one challenge is that it is difficult to enlarge the COMPASS calculus and physics courses to a larger class. This is mainly due to the difficulty with managing in-class activities in a large classroom; (2) another challenge is that students were with one professor in the COMPASS program for a year, in which students have had less chances to establish their understanding to calculus/physics from another faculty at the same institution. This can be seen as an advantages as well. Many students expressed their interests in the COMPASS program because of the small classroom setting in comparison with other sections (large lecture room, even though the enrolled students are between 50–90); (3) students identification can be critical process during the COMPASS program. In past two years, COMPASS has had students who did not do well on the pre-tests on mathematics, but they have the solid foundation in pre-calculus. This is mainly due to the technical problems when students answering the surveys online, though it can be because of the surveys were conducted prior college, students did not recognize the importance of the surveys. Further research on students' performance on their continuing mathematics courses is in progress.

ACKNOWLEDGEMENTS

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APPENDICES

4.1 An Example of Math Survey

Calculus ABC Test I—Version 2673 **Name:** ____________________

Lecture section: __________ **Student Number:** ______________

PUT ANSWERS IN BOXES. NO BOOKS/NOTES/CALCULATORS. DO YOUR OWN WORK. Simplify answers where possible. Include units where needed. All angles are in radians. $\log = \log_{10}$.

1. Simplify as far as you can:

$$\frac{x^2 - x - 2}{x^2 - 1}$$

2. Simplify by combining using a common denominator:

$$\frac{x}{x-4} - \frac{3}{x+6}$$

3. Solve for t:

$$\frac{1}{t-2} = 1 + \frac{2}{t^2 - 2t}$$

4. Solve for x:

$$\frac{x+2}{x-3} = 5$$

5. Solve for r:

$$|2r - 4| \geq 8$$

6. Find the equation of the line with x-intercept 2 and y-intercept -3 in *point-slope* form.

7. Find all roots of: $x^2 - 3x - 28 = 0$

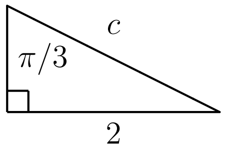
8. Find the value of:

$$\cos\left(\frac{\pi}{6}\right)$$

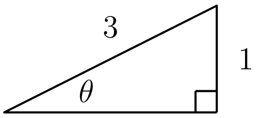
9. Find the value of:

$$\cos(0)$$

10. Find the value of c:



11. Find the value of $\tan(\theta)$:



12. Graph the function $y = \sin(x)$ for $-\pi \leq x \leq \pi$.
Label with the following values (if applicable): each intercept, location of each asymptote, and (x, y) coordinates of each min and max.

13. Simplify:

$$(-125)^{-1/3}$$

14. Simplify:

$$\left(x^2\right)^3$$

15. Solve for x (write answer as a rational number):

$$9^{2x-1} = 3$$

16. Solve for y:

$$2^{4y-3} = 12$$

17. Graph the equation $-x + y = 1$.
Label with the following values (if applicable): each intercept, slope, and (x, y) coordinates of vertex.

18. Graph the function $y = 2x^2 + x$.
Label with the following values (if applicable): each intercept, slope, and (x, y) coordinates of vertex.

19. Find the perimeter of a rectangle which has length 6 inches and width 3 inches.

20. Find the volume of a right circular cylinder (a can) with radius 5 cm and height 5 cm.

4.2 An Example of COMPASS Physics Lab

This is an example of the COMPASS physics lab for PH132 entitled “Is a Charging Train like an Accelerating Capacitor?”. The instructions are given to the students as described below:

1. **Goals:**
   (a) Model the motion of an electric train
   (b) See the similarities between an electric train and a charging capacitor
   (c) Find the time constant for the train

2. **Theory:** From your lectures, textbook and lab book, you have learned that a charging capacitor follows an exponential curve. More specifically, the charge on a capacitor in an RC circuit is given by

$$q(t) = q_m \left(1 - e^{\frac{-t}{RC}}\right) \tag{4.1}$$

   where q_m, the maximum charge, is given by $q_m = C\varepsilon$, C is the capacitance of the capacitor, R is the resistance of the resistor, and ε is the potential of the power supply.

   Without going too far into the modeling of the motion of the inner workings of an electric train, the equation for the velocity of an accelerating train looks very similar to equation 4.1:

$$v(t) = v_m \left(1 - e^{\frac{-t}{\tau_T}}\right) \tag{4.2}$$

   where τ_T is the time constant for the train. We will be looking at this value, as well as the maximum velocity v_m of the train for a given voltage. The maximum velocity for a given voltage can be modeled as

$$v_{max,t} = mV - b \tag{4.3}$$

   where V is the voltage applied across the tracks to make the train move. The terms m and b are constants to be determined in the data analysis.

3. **Data Collection and Analysis:** Set up the train on the tracks. Using the computer attached to the tracks, and the power supply, run the train and collect data starting with **4V**. Once you have the data, increase the voltage to **6V**. Repeat this process, raising the voltage by 2V every time, until you reach a maximum of **12V**. You should have **5** data sets when you are done.

4. **Velocity vs Time Plots:** As part of the experiment, you will obtain velocity data for different voltages. These curves should all be plotted on the same graph.

5. **Maximum Velocity vs Voltage Plot:** Using the data from the **velocity** vs **time** graphs, plot the maximum velocity vs the respective voltages. This should follow equation 4.3, enabling you to find the terms m and b from the slope and intercept of the plot.

6. **In-Lab Exercise:**
   A) Rearrange equation 4.2, solving for $ln\left(1 - \frac{v(t)}{v_m}\right) = \frac{-t}{\tau_T}$.
   B) What should the slope of the plot having $ln\left(1 - \frac{v(t)}{v_m}\right)$ on the y axis and t on the x axis be?
   C) Create **5** plots, one for each voltage, with $ln\left(1 - \frac{v(t)}{v_m}\right)$ on the y axis and t on the x axis.

D) τ_T **vs Voltage Plot:** The last plot will be of each τ_T value from the previous plots vs the appropriate voltages. This is to check if τ_T remains constant.

Note: If you want to see the full derivation of equations (4.1) and (4.2), ask your TA.

7. **Post Lab:** The questions are due one week after your lab:

(a) Following the Data Collection and Analysis section in the instructions, collect *velocity* data for the experiment. You should have **5** data sets for **4V**, **6V**, **8V**, **10V**, and **12V**.

(b) Plot the **velocity** data for each voltage on the same plot. You should have 5 curves, one for each voltage. Looking at where the curves level off, record the maximum velocity for each voltage in the table below.

(c) Plot the data in the table, v_m vs **Voltage**. Fill in the spaces under the table, with the values of m (the slope) and b (the intercept).

(d) Using Excel (or your preferred plotting program), calculate $ln\left(1-\frac{v(t)}{v_m}\right)$ for each velocity curve. Follow the instructions in your lab book, in the lab description, for help with this step. Plot $ln\left(1-\frac{v(t)}{v_m}\right)$ vs time for each data set. You may have to trim off the data if it starts to get noisy.

(e) What is the slope of your $ln\left(1-\frac{v(t)}{v_m}\right)$ vs time plot? Algebraically solve equation (4.2) for $ln\left(1-\frac{v(t)}{v_m}\right)$ to answer this question.

(f) From your $ln\left(1-\frac{v(t)}{v_m}\right)$ plots, find τ_T and record those values in the table below. Find the average τ_T.

(g) Does the value of τ_T seem to stay constant? Keep in mind the scale of the spread of the points.

(h) What does τ_T physically represent?

Plots to print out and hand in:

- One plot of *Velocity* vs *Time*, with 5 series of points, corresponding to 5 different voltages
- One plot of *Maximum Velocity* vs *Voltage**
- **Five** plots of $ln\left(1-\frac{v(t)}{v_m}\right)$ vs *time**
- One plot of τ_T vs *Voltage*
- The plots with a star (*) next to them should have trendlines and R^2 values. All plots should have labels and units.

Voltage	v_m	τ_T
4V		
6V		
8V		
10V		
12V		

m : ____________

b :____________

$\tau_{T,average}$____________