Assessment of physics course outcomes, general education outcomes, and ABET course outcomes of engineering majors, technology majors, and health sciences majors at a community college

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Abstract

Expected learning outcomes were assessed in physics laboratory courses designed for engineering majors, technology majors, and health sciences majors at the Queensborough Community College. The physics department's learning outcomes contribute to the college's general education outcomes and ABET course outcomes. Students were given two exams including a written test on basic math and a laboratory practical exam. The laboratory exam measured student ability to work with an air track or with electric field equipment, both commonly used in undergraduate physics education. Results illustrate that large percentages of students majoring in technology, and in the health sciences, need to improve their basic math skills and their ability to use laboratory equipment to meet the expected learning outcomes.

1) Introduction

This paper presents assessment results on how well three groups of STEM students learned a particular set of outcomes expected across physics courses. The assessment was conducted at the end of the fall semester of 2014 at the Queensborough Community College (QCC); QCC is part of the City University of New York (CUNY). In the fall of 2014 QCC enrolled more than 16,000 students and employed 391 full-time and 530 part-time Faculty [1]. QCC has an open enrollment policy meaning that any applicant with a high school diploma or equivalent GED is eligible for admission to an Associate's Degree Program [2]. It has been reported however that large numbers of graduating high school students are not ready for college [3,4]; and that in New York City and some surrounding communities the percentages of graduating students are much higher than those "college ready" based on their New York State Regents algebra exam scores [5]. This is a big concern because proficiency in Algebra II is expected for students entering STEM disciplines [6]. Although the college has an open enrollment policy our physics courses do have prerequisites; those designed for technology majors and health sciences majors have College Algebra and Elementary Trigonometry pre-requisites; and for engineering majors a pre-requisite of pre-Calculus and co-requisite of Analytic Geometry and Calculus I [1]. To determine if incoming students are math proficient QCC uses the SAT, ACT, or NY State Regents exam scores; otherwise placement tests in numerical skills, pre-algebra, algebra, and college algebra and trigonometry are used to determine the required level of math remediation [1]. It is important that the math placement exams adequately assess, and the remediation courses sufficiently prepare students for their majors. Sufficient levels of math preparation may increase retention and make stronger STEM graduates.

2) Data Formulation and Methodology

How well students learned the expected course outcomes was assessed for six physics lab courses totaling nine sections within the last week of a semester; this included 134 students on a written math exam and 87 students on a laboratory practical exam. Tabulated assessment results and the rubrics used to grade the exams are included. Table 1 lists the courses evaluated and the number of students per STEM major. The physics courses PH201 and PH202 are taken by technology majors, PH301 and PH302 are taken by chemistry majors and students in health science programs such as environmental health, medical laboratory sciences, diagnostic medical imaging, pre-medical, dental, and physical therapy majors; the physics courses PH411 and PH413 are taken by engineering majors. PH201, PH301, and PH411 are first semester physics courses in mechanics, PH202 and PH302 are second semester physics courses in electro-magnetism and optics, and PH413 is a third semester physics course in electro-magnetism. This paper focuses on the different results between PH201, PH301, and PH413 (PH411 results would have been a more direct comparison however an insufficient number of those students were tested). The set of expected learning outcomes common to the courses are indicated below as PHY 1, PHY 2, and PHY 3. QCC lists ten General Education outcomes; the expected learning outcomes evaluated contribute to QCC Gen. Ed. outcomes numbered 2, 3, 4, 5, and 9, and to Accreditation Board for Engineering and Technology Outcomes (ABET) which are also listed. Table 2 shows how the various Physics, Gen. Ed., and ABET outcomes are related.

The math assessment exam was taken over a period of 20 minutes, without calculators, and included the testing of basic math skills needed to solve physics problems. The exam was created by us for the purpose of this assessment (see Artifact 1). The first dimension, "Basic math," tested ability to add and multiply fractions, rearrange 3-variable algebraic equations, multiply and divide numbers expressed in scientific notation, recognize common geometrical formulas, use the Pythagorean Theorem, convert units, and add vectors. The second dimension, "Evaluating functions to produce data," measured ability to evaluate functions and tabulate their data. The third dimension, "Graphing," tested ability to draw plots of three functions widely used in first year physics. The hands-on laboratory practical exams were also created by us for the purpose of this assessment; they were 10 minutes long and tested ability to setup and use experimental equipment. For the mechanics lab courses students were asked to demonstrate their ability with the *Measurement of Gravity* experiment including the air track, glider, photo-gates and timer. The air track apparatus is used by students 3 to 4 times in a given semester. For the electro-magnetism lab courses students were asked to setup and demonstrate their ability with the *Electric Field Plot* experiment, which includes parallel line and point dipole electrodes, a voltage supply, voltmeter and probes. The electric field lab equipment is only used by the students once per semester.

Educational outcomes assessed:

- PHY 1: *Use algebra, geometry and trigonometry to describe physical situations and to solve physical problems* (assessed with artifact 1 dimensions 1 and 2).
- PHY 2: *Describe and analyze physical situations using graphical representations* (assessed with artifact 1 dimension 3).

- PHY 3: *Perform experiments and draw meaningful conclusions from data and present them as part of a clear, well-organized lab report* (assessed with artifacts 2 and 3).

- Gen Ed 2: Students will use analytical reasoning to identify issues or problems and evaluate evidence in order to make informed decisions.
- Gen Ed 3: Students will reason quantitatively and mathematically as required in their fields of interest and in everyday life.
- Gen Ed 4: Student will use information management and technology skills effectively for academic research and lifelong learning
- Gen Ed 5: Students will integrate knowledge and skills in their program of study.
- Gen Ed 9: Students will employ concepts and methods of the natural and physical sciences to make informed judgments.

- ABET 1: Demonstrate skills and knowledge for employment and advancement within the technology field.
- ABET 2: Demonstrate the ability to identify and solve technical problems, applying knowledge of mathematics, science, electronics, hardware, and software tools.
- ABET 3: Conduct experiments, as well as to analyze and interpret the data both individually and in a team setting.

3) Results

Figures 1 through 3 are made from data Table 3 and present the results from the Basic math component of the math exam for the different STEM majors. The percentages of students that scored in the *needs improvement* category were 49% for 1st semester technology students, 36% for 1st semester health science students, and 0% for 3rd semester engineering students. It is not surprising that the engineering students in PH413 outperformed the other majors as PH413 is a third-semester physics course requiring a higher level of prerequisite math. Figures 4 and 5 are from data Tables 4 and 5; these two figures present the results for the components of the math exam where students had to evaluate functions, and then plot functions. The percentages of students that *need improvement* in their ability to evaluate functions were 53% for 1st semester technology students, 53% for 1st semester health science students, and 4% for 3rd semester engineering students. In plotting functions the percentages of students that *need improvement* were 69% for 1st semester technology, 47% for 1st semester health sciences, and 9% for 3rd semester engineering. It should be mentioned that students were only asked to evaluate, and plot, three math functions thus if a student did not know how to evaluate just one of the functions their score dropped from *excellent* to *fair*; this, in part, explains the bimodal results shown in Figures 4 and 5. On a future test more math functions would appear on the exam. Students were asked to evaluate and then plot the same math functions therefore the results for these two parts of the exam are correlated.

Table 6 lists the results for the two laboratory practical exams. About 50% of students scored in the categories of *needs improvement* and *fair* when tested if they understood the measurement being made with the air track, and in their ability in using air track lab equipment. Figure 6 is made from data Table 7 and presents the overall test results. The assessment results for the air track mechanics lab peak about *good* whereas the electric field lab results peak about *fair*. It is not surprising that students performed better using the air track equipment considering that they use it 3 to 4 times per semester, unlike the electric field lab which is only taught once per semester. The varying levels of difficulty the two physics labs were not taken into account here. A summary of the results are presented in Table 8 emphasizing the areas in which the technology and health science students have the highest need for improvement in meeting the expected physics department outcomes, college General Education outcomes, and ABET outcomes. The grading rubrics are presented in Tables 9 through 11.

4) Exploration of causes of the observed deficiencies: student preparation and accountability

The percentages of health sciences students and technology students that scored in the *needs improvement* category on the three parts of the math assessment ranged between 36% and 69% (see Table 8); this resulted from their difficulties with converting units, adding vectors, recognizing geometrical formulas, and evaluating and plotting functions. On the other hand the percentages of engineering students that need improvement were 0% in basic math, 4% in generating data from functions, and 9% in plotting functions (see Figures 3, 4, and 5). It was expected that the engineering students were going to perform better on the exam since they were evaluated at the end of a 3^{rd} semester physics course, whereas the technology and health science students were evaluated at the end of a 1^{st} semester physics course; such a large difference in their performances however was not expected. These high percentages of health sciences and technology students that need improved math skills resembles the reported high percentage of high school graduates not prepared to enter college. Having a strong math background as well as good study habits are important for STEM majors to do well in their first college physics course.

The combined percentage of health science and technology students that scored in the needs improvement category in their *ability to use the air track equipment* was 17%, and in their *understanding of the air track measurement* was 28%. These large percentages are of concern considering the same equipment is used by the students 3 to 4 times per semester. Our lab students typically work in groups of 4 to conduct experiments, and do not have a lab practical exam on how to use the equipment. We have observed that when lab groups are not closely supervised some students wait for others to acquire the lab exercise data, which they share, and do not gain as much experience using the equipment. Since they know there is no exam they know they will not be held accountable. Our plan is to try to increase student accountability by experimenting with smaller lab groups, requiring a practical exam, and then repeating the assessment.

5) Conclusions

The technology program students were tested at the end of their first semester of physics, which they typically take during their third semester in college; they had the highest percentage of students that need improvement: 49% in basic math, 53% in evaluating math functions, and 69% in plotting functions. The results for first semester health science students were marginally better and for third semester engineering students were far better. Since engineering students begin at a higher level of pre-requisite math, and because they were tested at the end of their third semester of physics, it was expected that they would perform better than those from the other two STEM disciplines. Considering that the students from all three disciplines were expected to have learned the types of math they were tested on prior to entering these courses, it is concluded that providing a math-for-physics preparation could help. The lab skills assessment showed that 28% of technology students and health science students did not thoroughly understand the physics of the air track lab measurement, and that 17% need improvement in their ability to use this equipment. This poor result was unexpected considering that the air track equipment is used by the students 3 times per semester. A future assessment would explore if students perform better at using the laboratory equipment at the end of a semester if the number of students per lab group is reduced during the semester, and, if they are required to take and pass a lab practical exam. Better preparing students in basic math and holding them more accountable in laboratory classes may help them meet the course expected learning outcomes, the college's general education outcomes, and ABET program objectives.

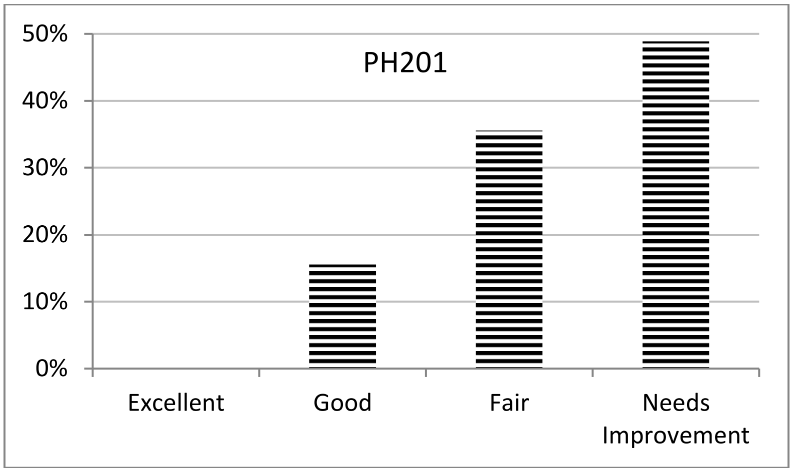

Figure 1: technology student performance on the basic math test. Date from Table 3.

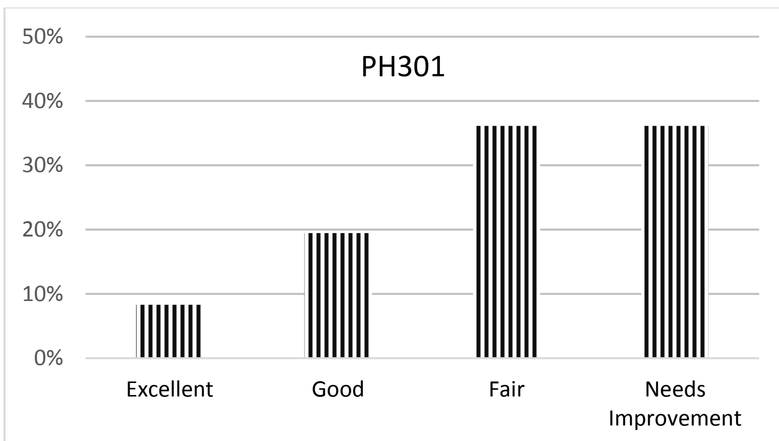

Figure 2: health sciences student performance on the basic math test. Data from Table 3.

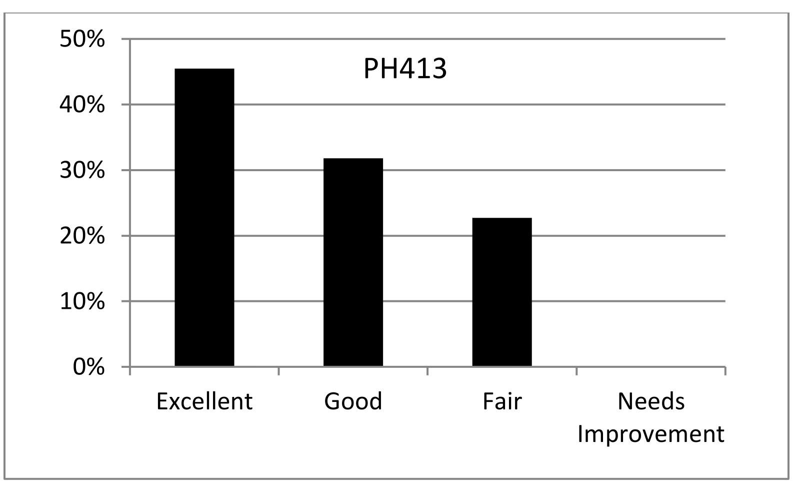

Figure 3: engineering student performance on the basic math test. Data from Table 3.

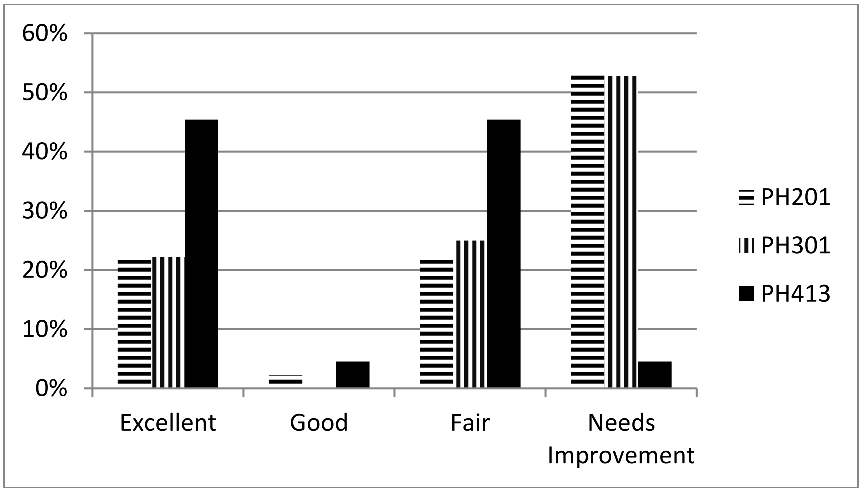

Figure 4: student performance in generating data from math functions for technology (PH201), health sciences (PH301), and engineering (PH413) majors. The bimodal distribution stems from the fact that students were only asked to evaluate three math functions and if they got just one wrong their score dropped from excellent to fair. Data from Table 4

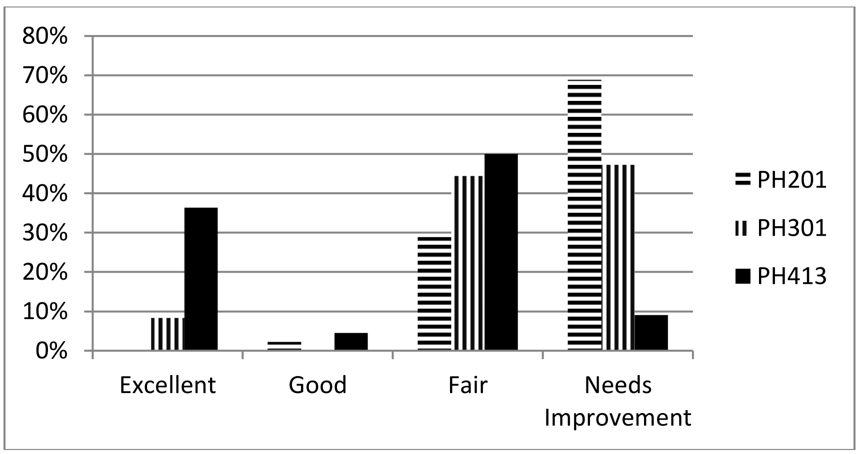

Figure 5: student performance in plotting data from math function for technology (PH201), health sciences (PH301), and engineering (PH413) majors. The bimodal distribution stems from the fact that students were only asked to plot three math functions and if they got just one wrong their score dropped from excellent to fair. Data from Table 5

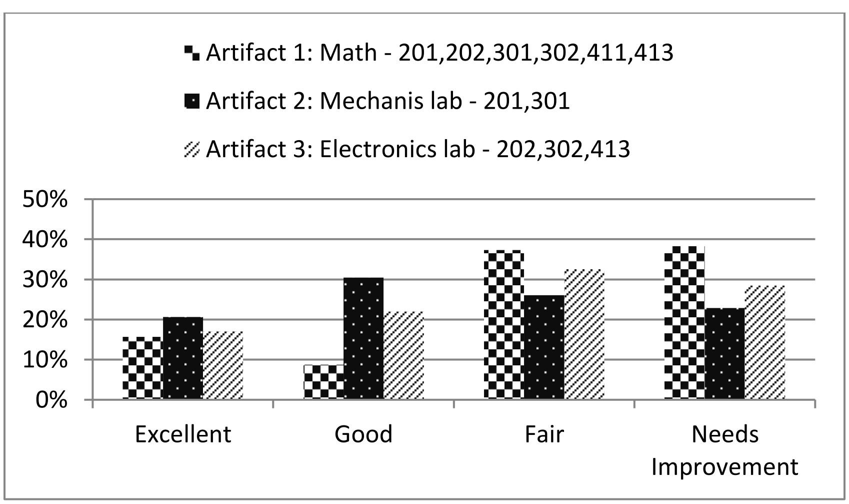

Figure 6: percentages of students from all three majors combined that scored on the math test (including basic math, evaluating functions, and plotting functions), and in their ability to use laboratory equipment. Data from Table 7.

References

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[6] "AAPT Statement on High School Physics Courses for College-Readiness in STEM Areas," AAPT executive Board, American Association of Physics Teachers, Jan. 2015. www.aapt.org/Resources/policy/Statement-on-High-School-Physics-Courses.cfm.

Artifact 1:

Physics Department Lab Course Assessment: PH201, 202, 301, 302, 411, 413.
20 minutes allowed test time; no calculators allowed

Basic Math Exam

Solve the following:

1) 1/2 + 4/5 =

2) 1/2 x 4/5 =

3)$f = m \cdot a,\ f = 5,\ m = 2, a = ?$

4) simplify this expression: $\frac{10^3 10^7}{10^{-11} 10^2} = ?$

5) The following formulas are used to calculate what properties and for which shapes?
y = mx + b
c = 2πr
A = πr^2
A = ½ bh
A = 4 πr^2
V = 4/3 πr^3

6) How long is the hypotenuse and what is the angle of a right triangle having opposite side O = 5 and adjacent side A = 3?

7) How many yards are in 6 meters? Use 1m = 100cm, 2.5cm = 1 inch, 36 inches = 1 yard

8) Vector **C** = **A** + **B** where **A** = -15**x** - 12**y** and **B** = -3**x** + 9**y**; what are the two components, the magnitude and the angle of **C**?

Generating data and Plotting Data

For each of the following functions create two columns of data over the period *t* = 0 seconds to *t* = 4 seconds, and draw a plot:

1) $velocity\ v(t) = a \cdot t$, where *a* = 5 m/$s^2$

2) $position\ x(t) = \frac{1}{2} a \cdot t^2$, where *a* = 5 m/$s^2$

3) $x(t) = A \cdot cos(\omega \cdot t)$, where *A* = 3 and $\omega = 2$ radians per sec

Tables

Lab Course	Major	Basic math, data & Plotting test (artifact 1)		Air track mechanics lab (artifact 2)		Electric field electronics lab (artifact 3)	
		sections	students	sections	students	sections	students
Physics 201	Technology	3	45	1	10		
Physics 202	Technology	1	14			1	14
Physics 301	Health Sciences	2	36	2	36		
Physics 302	Health Sciences	1	10			1	10
Physics 411	Engineering	1	7				
Physics 413	Engineering	1	22			1	17
Total		9 sections	134 students	3 sections	46 students	3 sections	41 students

Table 1: Numbers of course sections and students assessed

Physics Department course outcomes	Related QCC General Education outcomes	Related ABET course outcomes
PHY 1: *ability to use math*	Gen Ed 2, 3, 5	ABET 1, 2
PHY 2: *graphing*	Gen Ed 2, 3, 4, 5	ABET 1, 2, 3
PHY 3: *perform experiments*	Gen Ed 2, 4, 5, 9	ABET 1, 2, 3

Table 2: Physics course outcomes and their contributions to QCC General Education and ABET outcomes

Lab Course	Major	Students tested	Excellent	Good	Fair	Needs Improvement
Physics 201	Technology	45	0 (0%)	7 (16%)	16 (36%)	22 (49%)
Physics 202	Technology	14	0	1	9	4
Physics 301	Health Sciences	36	3 (8%)	7 (19%)	13 (36%)	13 (36%)
Physics 302	Health Sciences	10	1	5	4	0
Physics 411	Engineering	7	0	2	3	2
Physics 413	Engineering	22	10 (45%)	7 (32%)	5 (23%)	0 (0%)
Total		**134**	**14**	**29**	**50**	**41**

Table 3: Numbers (and percentages) of students that scored in each grading category on Basic math test

Course	Major	Students tested	Excellent	Good	Fair	Needs Improvement
Physics 201	Technology	45	10 (22%)	1 (2%)	10 (22%)	24 (53%)
Physics 202	Technology	14	2	1	9	2
Physics 301	Health Sciences	36	8 (22%)	0 (0%)	9 (25%)	19 (53%)
Physics 302	Health Sciences	10	3	1	5	1
Physics 411	Engineering	7	2	0	2	3
Physics 413	Engineering	22	10 (45%)	1 (4%)	10 (45%)	1 (4%)
Total		**134**	**35**	**4**	**45**	**50**

Table 4: Numbers (and percentages) of students that scored in each grading category when tested on ability to evaluate functions to produce data

Course	Major	Students tested	Excellent	Good	Fair	Needs Improvement
Physics 201	Technology	45	0 (0%)	1 (2%)	13 (29%)	31 (69%)
Physics 202	Technology	14	2	0	4	8
Physics 301	Health Sciences	36	3 (8%)	0 (0%)	16 (44%)	17 (47%)
Physics 302	Health Sciences	10	0	0	8	2
Physics 411	Engineering	7	1	0	3	3
Physics 413	Engineering	22	8 (36%)	1 (5%)	11 (50%)	2 (9%)
Total		**134**	**14**	**2**	**55**	**63**

Table 5: Numbers (and percentages) of students that scored in each grading category on ability to plot functions

Course	Dimension	Students tested	Excellent	Good	Fair	Needs Improvement
Physics 201 & 301 Air track Lab	Understands measurement of air track	46	7 (15%)	16 (35%)	10 (22%)	13 (28%)
	Ability to use air track lab equipment	46	12 (26%)	12 (26%)	14 (30%)	8 (17%)
Physics 202,302 & 413 E-Field Plot Lab	Understands measurement of E-field Lab	41	8 (20%)	11 (27%)	16 (39%)	6 (15%)
	Ability to setup E-field Lab	41	6 (15%)	5 (12%)	12 (29%)	18 (44%)
	Ability using E-Field Lab equipment	41	7 (17%)	11 (27%)	12 (29%)	11 (27%)

Table 6: Numbers (and percentages) of students that scored in each grading category when tested on ability to use the air track lab and electric field plot lab

Course	**Artifact dimensions**	**Students tested**	**Students tested multiplied by number of dimensions**	**Excellent**	**Good**	**Fair**	**Needs Improvement**
Physics 201,202, 301,302, 411 & 413	1) Basic math 2) data 3) Plotting	134	402	63 (16%)	35 (9%)	150 (37%)	154 (38%)
Physics 201 & 301	Air track lab	46	92	19 (21%)	28 (30%)	24 (26%)	21 (23%)
Physics 202, 302 & 413	Electric field lab	41	123	21 (17%)	27 (22%)	40 (33%)	35 (28%)

Table 7: Numbers (and percentages) of students in that scored in each grading category when tested on basic math, evaluating functions, plotting, and using laboratory equipment on the lab tests

Expected Student Learning Outcome measured	**What the artifact actually tested**	**General Education Outcomes associated**	**ABET outcomes associated**	**Artifact used to test outcome**	**Percent of students that need improvement**
PHY 1 (MATH): *Use algebra, geometry and trigonometry to describe physical situations and to solve physical problems*	Use basic math, algebra, geometry and trigonometry to solve physical problems	2, 3, 5	1, 2	Basic math test (1st dimension of 1st artifact)	PH201 49% PH301 36%
				Evaluating functions (2nd dimension of 1st artifact)	PH201 53% PH301 53%
PHY 2 (MATH): *Describe and analyze physical situations using graphical representations.*	Describe physical situations using graphical representations	2, 3, 4, 5	1, 2, 3	Graphing plots (3rd dimension of 1st artifact)	PH201 69% PH301 47%
PHY 3 (LAB): *Perform experiments and draw meaningful conclusions from data and present them as part of a clear, well-organized lab report.*	Perform experiments	2, 4, 5, 9	1, 2, 3	Understands air track lab measurement (1st dimension of 2nd artifact)	PH201 & PH301 combined: 28%
				Ability to use air track lab (2nd dimension of 2nd artifact)	PH201 & PH301 combined: 17%
				Ability to setup electric field lab (2nd dimension of 3rd artifact)	PH202, PH302, & PH413 combined: 44%

Table 8: Course outcomes having the highest need for improvement

Dimension	Needs Improvement (< 70%)	Fair (70-79%)	Good (80-89%)	Excellent (> = 90%)
Basic Math	Answered < 70% of questions correctly	Answered 70-79% of questions correctly	Answered 80-89% of questions correctly	Answered > = 90% of questions correctly
Evaluate functions to generate data	Incorrectly generates data such that it cannot be used to generate plots	Generates a minimal amount of the data correctly	Generates most but not all data correctly	Generates all the data correctly
Plotting data	Does not plot the data correctly	Plots a minimal amount of the data correctly	Plots most of the data correctly	Plots all of the data correctly

Table 9: Rubric to evaluate the Math test (artifact 1)

Dimension	Needs Improvement (< 70%)	Fair (70-79%)	Good (80-89%)	Excellent (>=90%)
Understanding of what is being measured	Insufficient understanding of what is to be measured to conduct an experiment	Partially understands, but not clearly, what is to be measured	Has a good enough understanding of what is to be measured to carry out an experiment	Excellent understanding of what is being measured
Ability using equipment	Does not understand how to use equipment to make measurements	Understands how to use some of the equipment	Has a good understanding on how to use most, but not all, of the equipment	Clearly understands how to use all of the equipment

Table 10: Rubric to evaluate the air track mechanics lab: measurement of gravity (artifact 2)

Dimension	Needs Improvement (<70%)	Fair (70-79%)	Good (80-89%)	Excellent (>=90%)
Understanding of what is being measured	Insufficient understanding of what is to be measured to conduct an experiment	Partially understands, but not clearly, what is to be measured	Has a good enough understanding of what is to be measured to carry out an experiment	Excellent understanding of what is being measured
Ability to setup equipment to conduct experiment	Does not setup enough of the equipment properly to make the measurements	Setup a minimal amount of the equipment properly	Setup most of the equipment properly	Quickly and properly setup all equipment
Ability to use equipment	Does not understand how to use equipment to make measurements	Understands how to use a minimal amount of the equipment	Clearly understands how to use most, but not all, of the equipment	Clearly understands how to use all of the equipment

Table 11: Rubric to evaluate the Electric field plotting electronics lab (artifact 3)