AC 2008-923: DIRECT ASSESSMENT OF STUDENT LEARNING OUTCOMES IN PHYSICS FOR ENGINEERS COURSES

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Direct Assessment of Student Learning Outcomes in Physics for Engineers Courses

Abstract

The calculus-based Introductory Physics sequence of courses for undergraduate engineering students is considered part of the general education requirement by most colleges and universities. However, as implied by the a)-k) general ABET program outcomes, and the l)-n) outcomes specific to Mechanical Engineering programs, a solid preparation in Physics is required in order for students to be successful in the further study of engineering disciplines, and ultimately become accomplished engineers. Thus a good direct assessment of student achievement in physics is as important as the direct assessment in the core engineering disciplines. With this in mind we decided to use recent methodologies applied for direct assessment of engineering courses to develop a direct assessment for calculus-based physics taught to undergraduate mechanical engineering students.

The paper describes our methodology for assessing student achievement in one of the Physics courses in the calculus-based Physics sequence, and the results we obtained for the past two academic years. Achievement of each Student Learning Outcome was determined quantitatively using a spreadsheet program. A special focus was placed on Student Learning Outcomes directly related to the a)-n) ABET required program outcomes for Mechanical Engineering programs. We found the methodology to be very helpful in assessing topics of difficulty for students, and year-to-year trends in student learning.

1. Introduction

Direct assessment of student learning outcomes[1] is a practice now embraced by a majority of colleges and universities with ABET accredited engineering programs. The way direct assessment methods are applied has been the subject of numerous journal and conference papers[2,3]. The present paper focuses on the ABET accredited Mechanical Engineering program offered at first author's institution, specifically on direct assessment of the General Physics III course. As such the paper brings into attention the Physics sequence of courses which is generally overlooked from the portfolio of engineering courses directly assessed by engineering departments, even though the knowledge acquired by students in these courses is a pre-requisite for many engineering disciplines.

The academic schedule at the first author's institution is based on three 10-week quarters: Fall, Winter, and Spring. Physics is studied in a year-long sequence of courses, taken by engineering students in their Sophomore year. Each calculus-based General Physics course is a 4-credit, 5-contact hours course, out of which 3 hours per week are dedicated to lecture, and 2 hours per week are dedicated to laboratory experiments. General Physics I is offered in Fall and covers Mechanics, General Physics II is offered in Winter and covers Electricity and Magnetism, and General Physics III is offered in Spring and covers Oscillations, Waves, Thermodynamics, Optics, and Modern Physics.

The paper describes our methodology for assessing student achievement in the General Physics III course, and the results we obtained in the 2005-06 and 2006-07 academic years. The authors are currently applying the same methodology to the General Physics I, and General Physics II courses. The results obtained will be presented in a future paper.

2. Description of General Physics III Student Learning Outcomes vs. ABET Program Outcomes

Student Learning Outcomes (SLO) express in condensed form the knowledge and abilities students must acquire in each course they complete. By providing the SLO's to students at the beginning of the quarter, they are able to track their progress throughout, and take responsibility for their achievement in the course. On the instructor side, the various assessment tools used to gather information about students' knowledge and abilities have to be developed with the SLO's in mind.

In the General Physics III course the Student Learning Outcomes are as follows:
1. Analyze and interpret oscillatory motion and simple harmonic motion, and perform calculations of the vertical mass-spring system and the simple pendulum.
2. Analyze and interpret wave motion, transverse and longitudinal waves, and wave equations, and perform calculations of transverse waves along a stretched string.
3. Formulate the concepts of superposition and interference; analyze standing waves, sound waves, and the Doppler effect.
4. Interpret the concepts of temperature, heat, and phase change, and perform calculations with temperature scales, heat capacity, and specific heat.
5. Conceptualize the model of the ideal gas, perform calculations using the ideal gas law, and analyze and interpret the kinetic theory of ideal gases.
6. Interpret the first law of thermodynamics, and calculate and predict work, heat, and internal energy change for various thermodynamic processes.
7. Interpret the concepts of reversibility, second law of thermodynamics, and entropy, and analyze heat engines and refrigerators.
8. Analyze and interpret the concepts of reflection and refraction of light and geometric optics. Perform calculations using Snell's law.
9. Formulate the concepts of images and optics including virtual and real images, focal length, diverging and converging lens, and spherical and chromatic aberration. Perform calculations using lens makers equation.
10. Interpret the concepts of interference and diffraction in physical optics; analyze and apply Huygens' Principle and the Rayleigh Criterion.
11. Interpret the concept of photon and the photoelectric effect, and formulate the Bohr atom theory and atomic spectra.

At first author's institution the General Physics III course is a pre-requisite for the engineering Thermodynamics course. Correspondingly, achievement in SLO's 4 - 7 can provide an indication of how well students are prepared to enter the Thermodynamics course. In addition, achievement of SLO 1 can show how well students are prepared for the study of Vibrations, a senior level engineering course.

ABET, the Accreditation Board for Engineering and Technology, states the importance of a solid Physics education in the preparation of future engineers in its criteria for accreditation. The 2007-08 Engineering Accreditation Commission criteria[4] for accrediting undergraduate programs require the following Program Outcomes (PO) for all engineering programs:

a. An ability to apply knowledge of mathematics, science, and engineering.
b. An ability to design and conduct experiments, as well as to analyze and interpret data.
c. An ability to design a system, components, or process to meet desired needs.
d. An ability to function on multi-disciplinary teams.
e. An ability to identify, formulate and solve engineering problems.
f. An understanding of professional and ethical responsibility.
g. An ability to communicate effectively.
h. The broad education necessary to understand the impact of engineering solutions in a global and societal context.
i. A recognition of the need for, and an ability to engage in lifelong learning.
j. A knowledge of contemporary issues.
k. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

In addition, the following Program Outcomes specific to Mechanical Engineering programs are required:

l. Knowledge of chemistry and calculus-based physics with depth in at least one.
m. The ability to apply advanced mathematics through multivariate calculus and differential equations; familiarity with statistics and linear algebra.
n. The ability to work professionally in both thermal and mechanical systems areas including the design and realization of such systems.

PO's a, b, and l relate directly to the requirement to study Physics as a fundamental science discipline with laboratory. The Physics lab where students work in teams with colleagues from various programs also prepares students to meet PO's d and g. In addition, the Physics education plays a role in the preparation of students to meet PO's h, i, and j.

All SLO's of the General Physics III course are appropriate for meeting the Program Outcomes mentioned above. Moreover, SLO's 4 - 7 are especially important in preparing students for the study of Thermodynamics, and ultimately for professional work in the "thermal systems area" as required by PO n, while SLO 1 is important for professional work in the "mechanical systems area" also addressed by PO n.

Table 1 summarizes the relationships between the General Physics III SLO's and the ABET PO's for Mechanical Engineering programs.

SLO\PO	a.	b.	c.	d.	e.	f.	g.	h.	i.	j.	k.	l.	m.	n.
1.	X	X		X			X	X	X	X		X		X
2.	X	X		X			X	X	X	X		X		
3.	X	X		X			X	X	X	X		X		
4.	X	X		X			X	X	X	X		X		X
5.	X	X		X			X	X	X	X		X		X

6.	X	X		X			X	X	X	X		X		X
7.	X	X		X			X	X	X	X		X		X
8.	X	X		X			X	X	X	X		X		
9.	X	X		X			X	X	X	X		X		
10.	X	X		X			X	X	X	X		X		
11.	X	X		X			X	X	X	X		X		

Table 1. Mapping of General Physics III Student Learning Outcomes to ABET Program Outcomes.

3. Direct Assessment Results for General Physics III course

Achievement of the Student Learning Outcomes in the General Physics III course is directly assessed with a variety of tools, which include weekly homework sets (H), quizzes (Q), laboratory reports (L), midterm exam (M), and final exam (F).

Results are presented and discussed in the following for two academic years: 2005-06 and 2006-07. One note about the results refers to the student populations in the two years that were quite different in size: 5, respectively 20 students.

Table 2 shows the average and median results obtained with each type of assessment, normalized to a maximum of 100, as well as the total weighted average and median results for each academic year.

	H	**Q**	**L**	**M**	**F**	**Total (weighted)**
Avg. 2006	85	81	88	91	80	**84**
Med. 2006	87	85	92	90	81	**86**
Avg. 2007	75	69	82	71	69	**73**
Med. 2007	82	69	88	75	73	**78**

Table 2. Grade distributions for the two academic years considered.

The results show that, in general, the grades obtained for work done at home (H and L) are higher than those for tests given in class (Q, M, and F). This is expected, due to the time limit and resources restrictions that characterize tests given in class, but not work done at home.

It is interesting to compare the results from the two academic years. For all assessment categories, the results in academic year 2005-06 were considerably better than the ones in 2006-07. Part of the difference can be attributed to the small class size of 5 students in 2005-06 resulting in less significant statistical data. As median parameters are less sensitive to the presence of 'outliers' than average parameters, it is better to compare the medians from the two academic years. The biggest differences between medians are seen in the quizzes, 16, and the midterm exam, 15, categories. By contrast, the differences in medians were 5 for the homework, 4 for the laboratory reports, and 8 for the final exam categories. A difference of 8 points was also observed in the median of the total scores.

In addition to the different class sizes in the two academic years, it must be noted that different textbooks were used in the two classes. A new textbook was introduced in academic year 2006-07. The new textbook came accompanied by a variety of supporting resources for the instructor, which were not available with the old textbook. Among these is the Test Generator program, which allows for easy creation of Quizzes and Tests. Due to the availability of this feature a new set of Quizzes, and a modified Midterm Exam were used in academic year 2006-07 compared to 2005-06. For example, more concept questions were included in the quizzes. However the Final Exams in the two academic years were very similar.

As the Final Exams were written to cover the majority if not all of the SLO's, they serve as a good tool to reflect achievement of SLO's by students in each academic year. Table 3 shows the average percentage obtained per SLO in each of the academic years considered. The goal we are striving toward is to obtain an average percentage of 70 or higher for each SLO.

Problem	**Weight**	**SLO**	**% 2005-06**	**Problem**	**Weight**	**SLO**	**% 2006-07**
F1, F2	0.07	1	95	F1, F2	0.07	1	70
F13	0.13	2	88	F13	0.13	2	65
F3, F4	0.07	3	70	F3, F4	0.07	3	74
F5, F6	0.07	4	90	F5, F7	0.07	4	78
	0	5		F6	0.03	5	68
F14	0.17	6	74	F14	0.17	6	61
F15	0.03	7	68	F15	0.03	7	38
F7	0.03	8	100	F8, F11	0.07	8	77
F8, F18	0.13	9	80	F9, F18	0.13	9	62
F9, F10, F16, F17	0.23	10	82	F10, F16, F17	0.2	10	78
F11, F12	0.07	11	60	F12	0.03	11	100

Table 3. Assessment of Final Exam in each academic year.

A first observation looking at Table 3 is that for SLO 10, "Interpret the concepts of interference and diffraction in physical optics; analyze and apply Huygens' Principle and the Rayleigh Criterion" there were four questions addressing it in 2005-06, and three questions in 2006-07. It must be noted that it is not possible to have exactly equal weights of each SLO in the final exam, due to the fact that the concepts and types of problems associated with each SLO differ. Additionally, the SLO's corresponding to the second half of the quarter carry more weight in the final exam than the SLO's from the first half which were also addressed in the midterm exam. However there seems to be a disproportionate weight of SLO10 in the final exam, which will be taken into account next time the course is taught.

The results show that in 2005-06 there were two SLO's with average percentages less than the goal of 70, while in 2006-07 there were five such SLO's, including one for which the average percentage was as low as 38! There was one overlap in the above SLO's, this was in SLO 7, "Interpret the concepts of reversibility, second law of thermodynamics, and entropy, and analyze heat engines and refrigerators". Here the average percentage dropped from 68 to 38 from first year to the second year considered. This constitutes a strong 'red flag' for the instructor, who will have to expand on the explanations and example problems associated with this SLO next time to assure that students understand it and can solve problems.

The next 'red flag' is raised by the 2006-07 results, where three of the four SLO's related to Thermodynamics had averages less than 70. As mentioned before, Thermodynamics is important for preparing future Mechanical Engineers to work professionally in the area of thermal systems design. The instructor will need to address the more difficult ideal gas law, and first and second laws of thermodynamics chapters with special care in view of the results obtained.

Finally, a true year-to-year trend will require continuing collection of data in the upcoming years. To facilitate data comparison and interpretation the instructor will take care in using similar content and difficulty in assessment tools such as quizzes and tests.

4. Conclusions

We found the methodology presented for assessing the achievement of students in the General Physics III course to be very helpful for the instructor. Features that can be easily extracted with this methodology include how well the exams written by the instructor match the Student Learning Outcomes, and what topics are the most difficult for students to master. Year-to-year trends which might require intervention from faculty are also evidenced.

The authors are now working on using the same methodology to analyze and interpret the data from the General Physics I and General Physics II courses. These will be presented in a future paper. Our intent is to continue the process of data collection and analysis for all three Physics courses in the undergraduate engineering sequence.

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