ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

New Orleans JAZZED about Engineering Education

Paper ID #14650

Ten Ways to Improve Learning Physics as Part of an Engineering Course

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ABSTRACT

Learning is a process. The assessment of learning is a powerful diagnosis that allows teachers to redirect their efforts towards assisting the weaknesses of the learning process as presented by students. This paper discusses 10 ways to improve learning Physics as part of an Engineering Course that adopt direct and indirect learning support actions. Each action is analyzed in connection to its own theoretical reference, the steps for implementing it, its challenges and needs, and students' and teachers' points of view. The actions discussed were applied to a Physics I course for freshman students at our Engineering School (a university with 1000 students—700 Day/300 Night). These Learning Support Actions are initially divided into indirect learning actions (student activities to improve learning without any evaluation grades, namely, 1.Student support; 2.Technical Staff; 3.Video classes, and 4. Teaching service) and direct learning actions (student activities to improve learning with evaluation grade, namely, 5. Online exercises; 6. Pre-Exam; 7. Laboratory reports; 8. Active Learning Projects; 9. Laboratory Seminars, and 10. Preparatory Discussion Laboratory Questions).

Keywords: Physics, Engineering Education, Active Learning

Introduction

Learning is a process. The assessment of learning is a powerful diagnosis that allows teachers to redirect their efforts towards assisting the weaknesses of the learning process as presented by students. This paper discusses 10 ways to improve learning Physics as part of an Engineering Course that adopt direct and indirect learning support actions. The actions discussed were applied to a Physics I course for freshman students at our Engineering School (a university of 1000 students—700 Day/300 Night) [1].

Direct and indirect learning support actions

With the aim to get the students more engaged in their course[2,3,4] and at the same time to help them develop different skills that are necessary for their future professional careers, the implemented learning support actions took into account that each student has different grades of facility regarding their particular way of learning (visual presentations, solving problems, etc.). These Learning Support Actions are initially divided into indirect learning actions (student activities to improve learning without any evaluation grades, namely, 1.Student Support; 2.Technical Staff; 3.Video classes, and 4. Teaching service) and direct learning actions (student activities to improve learning with evaluation grades, namely, 5. Online exercises; 6. Pre-Exam; 7. Laboratory reports; 8. Active Learning Projects; 9. Laboratory Seminars, and 10. Preparatory Discussion Laboratory Questions).
Each activity is discussed with regard to its own theoretical reference, the steps for implementing it, and its challenges and needs. In addition, students' and teachers' points of view are presented subsequently.

Student support

Characteristics: Weekly assistance for students with good academic performance in previous years - answering questions[5].
Steps for implementing this support: A student from a previous year that demonstrates good academic performance is available to support the freshman student. This aid basically consists of a resolution of exercises and concept enforcement.
Challenges and needs: The academic performance of students is not the only requisite, as also students with good soft skills are required. It is important that the student support schedule is readily available when help for the freshman student is needed. The results show that the best practice was attained when there was strongly disseminated support among students.

Technical Staff

Characteristics: Weekly teaching service - answering questions / performing exercises[5].
Steps for implementing technical staff support: an instructor is available once a week (8 h) to help the student solve exercises and explain physics concepts to clarify his/her doubts.
Challenges and needs: It is important that the of instructor support schedule is is readily available when help for the freshman student is needed. Moreover, students are sometimes ashamed and do not seek help. The results show that the best practice was attained when a specific topic was scheduled for attendance instead of by ways of arbitrary advice.

Video classes

Characteristics: The results show that the best practice was attained when short video lessons (about 5–10 minutes) were made available to students through video systems like YouTube[6,7].
Steps for implementing video classes: a short video about a specific Physics topic is made available to students. During the video, the professor purposes a discussion about the topic and solves one exercise on the blackboard. The students have to solve another exercise to learn the concepts described in the video.
Challenges and needs: The video is a fast tool for showing physics concepts and allows students access anytime and anywhere. The teacher should encourage students to practice their exercises and make an attractive video to challenge students. The results show that the best practice was attained when short videos were made available along with similar exercises.

Teaching service

Characteristics: Weekly service for teachers of the discipline - answering questions[5].
Steps for implementing the service: A teacher is available once a week (4h) to help the student with his/her doubts.
Challenges and needs: It is important that the teacher support schedule is readily available when help for the freshman student is needed. Moreover, students are sometimes ashamed and do not seek help. The results show that the best practice was attained when a specific topic was scheduled for attendance instead of by ways of arbitrary advice.

Online exercises

Characteristics: Individual evaluation by means of questionnaires using the MOODLE[8,9,10,11]. The subject of the questionnaires concerned the subjects taught during the two previous weeks. The questionnaires were usually composed of ten questions summarizing these taught topics. One of the most attractive functions of the MOODLE platform is the frequent online quiz, which gives student access to quizzes by means of modern technology (smartphones, computers, tablets, etc.), which catches their attention and makes the learning process friendlier. In an extra online class quiz, students can review the taught physics concepts periodically, while avoiding accumulating subjects without previously studying for final tests. Through this online quiz, students can also control their learning, by identifying their points of doubt, correcting themselves by means of feedback, and asking for help from the online moderator. Another important advantage is that each student can learn at his/her own pace, since the activity is not synchronous; rather, it gives them the opportunity to review previous basic concepts and to clarify them.

Steps for implementing the online exercises: As first step, the questionnaires were composed of 7 to 10 questions presenting different types of multiple choice, namely, true or false, matching, and short answers[12].The students were allowed two attempts. At this phase, the tests were elaborated according to different levels[13] of difficulty: some aimed to check students' ability to reproduce the examples that were given in class, while other presented a higher level of difficulty, in order to stimulate students' creativity. After each attempt, students received feedback with some clues to guide them to understand their mistakes and provide help for the next attempt. In the second phase, the general characteristics of the questionnaires were maintained, but in this process many repeated questions and lack of practical questions were identified as a failure. Trying to overcome the problem of repeated questions among the different attempts of each student, the calculated and embedded answers **(**Cloze) were introduced to enable the values of the questions to change and the question bank was increased. Some practical questions connecting theory classes with laboratory classes were also introduced, with the aim for students to develop a comprehensive view of the course as well as the capacity for modeling practical problems. As calculated questions with a higher level of difficulty were added, feedback for students likewise had to be improved compared to the previous level of questions[12], thus the solution of the calculated questions were made available to students at the end of each questionnaire.

Challenges and needs: The necessity to implement extra class activities in order to make students review physics concepts was shown to be imperative to helping students maintain their rhythm of studying and to avoiding an accumulation of subjects to be studied, as was the case previously[12]. The main challenge is to gain the students' interest, to enhance their engagement with the course, and to keep them involved in the proposed extra class activities[14,15,16]. Some factors have to be considered when implementing this online activity, such as the attributed importance of the obtained grades in the final mark (best practice was attained at about 10%), the commitment of the teaching staff's encouragement of students, and the moderator´s constant presence[14,16] .

Pre-Exam

Characteristics: Assessment, without consultation, made in pairs, consisting of numerical and conceptual exercises related to content that is developed each two months[1,17,18]

Steps for implementing pre-exams: issues are taken from textbooks or old exams.

Challenges and needs: time management is a challenge for students. Usually, they are not used to managing time in assessment, so this is a good opportunity for learning this. Discussion with peers is a good way to share knowledge and to increase student groups for learning. The results showed that assessment by means of two questions during approximately one hour was the best practice.

Laboratory reports

Characteristics: Weekly evaluation, done in teams of three students, consisting of experimental surveys and related analyzes[19,20,21]. Traditional writing reports often create a barrier for students' comprehension of physics concepts. Some alternatives have been discussed, such as oral presentation, visual presentation (poster), and homework[20,21]. According to a previous study[20], the use of alternative ways to report laboratory data allowed students to develop different skills (oral, visual, and written skills) in terms of reporting data. The necessity of developing such different skills is imperative for their professional lives[3].
Steps for implementing laboratory reports: Laboratory experiments must promote[22]: experimentation, analytical skills, conceptual learning, understanding the basis of knowledge of Physics, and developing collaborative learning skills. Blooms Taxonomy is a good way to implement laboratory methods for developing critical thinking.
Challenges and needs: The introduction of written or oral reports to freshman students was conducted according to a step-by step-process. Initially, a model of the written or oral presentation was provided. Teacher feedback is fundamental for providing significant improvement. The results showed that the best practice was attained when a report is done in class and the teacher gives feedback in the next class meeting. In addition, laboratory questions for which the highest levels of Blooms Taxonomy are required improve students' learning efficiency.

Active Learning Projects

Characteristics: Biannual assessment, conducted in similar teams of three students per laboratory class, consisting of scripts with conceptual issues and the analysis from related simulations[1,24,25,26,27].
Steps for implementing active learning projects: Working in groups, students are presented with certain scripts with problems that make use of prior knowledge (already acquired in class) and new knowledge (which will be taught to them later) as extra class activities. The teacher serves as facilitator and moderator of these activities. This project used a Problem Based Learning–PBL approach (with simulations and analysis). Each semester, four student teams received contextualized scripts, usually three scripts with problems for which they were required to conduct simulations and provide conceptual analysis, sometimes using PhET Activities[28]. At the end of each semester, they presented their results in an oral presentation (approximately ten minutes long) and had to pass both an oral and individual evaluation test.
Challenges and needs: The most successful results were related to students' motivation in Physics class. Students' commitment improved throughout the academic year, because they came to see the relationship between Physics and real world projects more clearly. Moreover, the teachers' team improved their learning approach, including some teachers that had never worked with the PBL approach. At our school, teachers' teams are composed of Physics and Engineering teachers, so this provided an opportunity to exchange different applications of physics concepts. The principal needs are related to the changes of some problems with the activities. These annual changes are necessary to avoid students' "copy and paste" practice from one year to other.

Implementing similar activities at others schools would first demand the commitment of teachers' teams. It is not difficulty to develop activities, but they demand time and work.

Laboratory seminars–(Laboratory Oral Report)

Characteristics: Annual assessment, made in similar teams of three students per laboratory class, consisting of an oral presentation of the objectives, methods, and results achieved by means of a determinate experiment[29].
Steps for implementing laboratory seminars: Each laboratory team is selected to present one presentation of the objectives, methods, and results achieved by means of a determinate experiment. The presentation must include the following items: objective, materials, results, and conclusion. The evaluated items were audibility, readability, capacity of organizing experimental data, and conclusions. The seminars were five to ten minutes of length, and all members of the laboratory team had to participate.
Challenges and needs: Introducing these oral reports to freshman students was conducted according to a step-by step-process. Before initiating the seminars in sequence, a model for the presentation was provided. Since each group had to present only one seminar per year, the first few groups had a higher difficulty than the last ones (this factor was taken into account during the evaluation). After each seminar the teacher gave feedback to the group and to the class, and as a result the seminars demonstrated a significant improvement.

Preparatory Discussion Laboratory Questions.

Characteristics: Individual weekly evaluation applied to students as a way to prepare them for the laboratory. The evaluation consists of conceptual questions regarding the experiment that is performed[30,31].
Steps for implementing discussion questions: The student must answer a few conceptual questions prior the laboratory class. The teacher does not correct errors individually, but analyzes the results as a whole.
Challenges and needs: Although some students simply copy texts from their fellow students, the vast majority do not. When students come to class better prepared, this improves their performance. The results showed that to offer approximately five issues related to the conceptual part of the experiment and not to the operational part constituted the best practice. The teacher only evaluates whether results are presented; students do not receive additional notes, but can be penalized if they do not hand in the activity.

Learning support actions analyses

The main question to be answered in this article is whether there is a relation between the various actions of support and student learning.

Teacher's perception

To answer this question, from the teacher's perspective, first SWOT analyses (Strengths, Weaknesses, Opportunities, and Threats) were applied to each of the actions of support.

Table 1—Actions of support–SWOT analyses–Teacher's perception

	Action	Strengths	Weaknesses	Opportunities	Threats
1	Student support	Personalized and individual attendance	Schedule	Contact between freshman and sophomore students	No guarantee of continued work
2	Technical Staff	Large room attendance	Schedule	Focus on specific exercises review	Inhibition of students
3	Video classes	Mass dissemination	Short videos—quick concepts review	Flexible time access	Quality of connection to access media
4	Teaching service	Personalized and individual attendance	Schedule	Contact between students and teachers can allow more help with pedagogical issues	Inhibition of students
5	Online exercises	Individualized assessment enabling rapid diagnosis and feedback. The technology must serve the concepts, not vice versa.	Repetition of questions	Better appointment for studying	The technology must serve the concepts, not vice versa.
6	Pre-Exam	Flag evaluation of the student's need to study and gain more organized behavior	Achievement in pairs can mask individual performance	Review of the subjects near exam period	No guarantee of all students conducting team work
7	Laboratory reports	Skills and attitudes improvement	Achievement in teams can mask individual performance	Better understanding of physics modeling	No guarantee of all students conducting team work
8	Active Learning Projects	Active student learning through open problems and simulations	Resistance "status quo" (students want a more passive	Development situations that promote greater conceptual understanding	Need of new problems proposed for each year

			position)		
9	Preparatory Discussion Laboratory Questions.	Promoting better organization of students regarding experiments that will be conducted	Not fraud-proof	Improves the performance of the laboratory class thanks to students' adequate preparation	Questions should encourage understanding and prepare students
10	Laboratory seminars	Review of concepts in addition to developing non-technical skills	Risk of becoming repetitive work	Involves communication skills	Adjusting time of the class schedule

Student's perception

A student survey was also applied, using a Likert scale of 5 degrees (very reasonable, little, very little, and cannot rate). A total of 605 students answered the questionnaire, representing approximately 50% of all students enrolled in the course (both night-time and day-time classes). On average, the survey was carried out by means of three issues for each evaluation item.

Table 2—Answers answered as Very or Reasonable

Number	Action	Learning Support	Engagement study	Better appointment for studying
1	Student support	16.1%	-	-
2	Technical Staff	32.4%	-	-
3	Video classes	74.0%	-	-
4	Teaching service	7.3%	-	-
5	Online exercises	60.0%	83.0%	86.0%
6	Pre-Exam	87.0%	-	78.7%
7	Laboratory reports	74.6%	-	-
8	Active Learning Projects	80.0%	81.0%	
9	Preparatory Discussion Laboratory Questions	-	-	63.7%
10	Laboratory seminars	62.0%	-	-

According to the table, the results show that the periodic quizzes according to the Moodle platform contributed greatly to students' learning and helped them to maintain a study rhythm. In terms of the role of these questionnaires in increasing students' engagement with the discipline, approximately 83.0% of students believe that these questionnaires helped them at least fairly. Pre-Exam has greatly contributed, performed 15 days before the tests and providing feedback the following week–87.0% very or reasonable), which helped students to maintain a good pace of study - 78.7% very or reasonable.
It should be stated that the reports enabled a better understanding of physics concepts (74.6% very or fairly); that 58.0% of respondents admit that the compulsory Preparatory Discussion Laboratory Questions became an important resource for students' learning, especially for students who would not read scripts previously if they were not preparatory issues. At the same time, it can be seen that the Seminars allow for a better understanding of physics concepts (very or reasonable, according to the opinion of 62.0%).
Finally, it was shown that Active Learning Projects that work primarily with a methodology based on closed and open problems, modeling, simulation, and analysis, had the highest rate of engagement and motivation (81.0%), which demonstrates the strong impact of actions to support learning.

Final considerations

The use of multiple forms of learning support is satisfactorily perceived by students and teachers, corroborating significantly to the teaching-learning process. Balancing support activities for direct or indirect learning support proved to be a wise option. According to the authors' perception, the most successful results are related to students' motivation and commitment in Physics class. Students' commitment must always be encouraged, throughout the academic year. Implementing similar activities in others schools will demand planning efforts and commitment from teachers' teams.

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