# A case study on the use of practical problem-solving activities to quantitatively improve physics learning in engineering education

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## Abstract

Problem-based learning uses real world problems to motivate students to identify and apply research concepts and information. Student centered learning methodologies have been gaining strength in Brazilian education institutions. Within this context, the present work is inserted, since an evaluation of an "Energy Power Plant" PSA (Practice-Supervised Activities) applied to Engineering courses was performed through the assessment of the student's knowledge before the start of the activity and after its conclusion. For this work, up to 444 questionnaire results were collected regarding engineering students in the first semester of their under graduate course and, at least 327 test results about students in the second/third semester. On the overall proportion of correct answers, the 1$^{st}$ semester students showed a higher improvement in comparison to the 2$^{nd}$ and 3$^{rd}$ semester students. Nevertheless, it should be noted that the starting knowledge level of the 2$^{nd}$ and 3$^{rd}$ semester students is higher than the 1$^{st}$ semester students. A comparison among 1$^{st}$, 2$^{nd}$ and 3$^{rd}$ semester students divided by specific engineering fields evidenced that the percentage of correct answers varies according to the different student profile among each specific course. So, the statistical methodology used, showed the knowledge gained by students where the practical aspect is an important component.

## Keywords

Engineering education, learning through practice, problem-solving, energy power plant.

## 1. Introduction

Nowadays, one of the major challenges for educators in the field of physics is to promote links to build the student's scientific knowledge. Specifically, in engineering courses, these links need to be built based on both theory and practice, valuing the "learning through practice". In order to accomplish that, the didactic strategy should involve teaching methodologies based on "problem-solving" to stimulate the student's intellect through action (Salvador 2000). The use of learning methodologies based on groups that study engineering education has been supported by several studies that justify the application of cooperative learning (Johnson and Johnson 1994), project-based learning or problem-oriented learning (Gijselaers 1996, Chinowsky et al. 2006). These methodologies share the idea that students work together to learn and are responsible for their own as well as others' learning (Slavin 1995). Furthermore, the group work challenge allows students to experience the conflicts, difficulties and limitations of some group members. This fact is a learning for real life, reported by the own students.

Problem-based learning is suitable for introductory sciences and engineering classes because it helps students to develop skills and confidence to formulate problems they have never seen before (Smith et al. 2005) and is appropriate for learning different competences in the field of engineering (Mesa et al. 2010, Mozas-Calvache and Barba-Colmenero 2013).

Student centered learning methodologies have been gaining strength in Brazilian education institutions. In particular, engineering courses are a good example of successful applications of "learning through practice" approaches (Graaff and Kolmos 2007). Following this path, the Physics Education Research Group (GruPEFE), at Paulista University (UNIP) started a series of "Practice Supervised Activities" (PSA). On these activities, the students must build and simulate, at a smaller scale, common engineering practices (Ferreira et al. 2014). This project approach includes designing and improving solutions for real-world problems; a key goal for engineering students (Soares et al. 2013). To support these activities, it is provided a technical manual that at the same time presents the problem/situation that needs to be solved and promotes an interface between the student and the theoretical knowledge that is being studied. (Karapetrovic and Rajamani, 1998).

The student needs to be protagonist of the construction of his own knowledge, and to do that, he needs to work on top of the reality, understanding the meaning of his own experimentation during the process of developing the PSA, acting on the environment through the processes of assimilation and accommodation (Salvador 2000). In this context, the student needs, specially, to be conscious that he is also an agent of production of his own learning, while the teacher plays the role of a mediator that makes possible the construction of his knowledge (Freire 2011).

To evaluate the whole student's learning process, it is necessary to follow, continuously, the development of the PSA closely. This follow up provides the teacher with a prospect and information about the student's knowledge development and about the quality of the teaching-and-learning process itself that happens through the interaction with the problem/situation proposed by the student-student and student-professor pairs (Karapetrovic and Rajamani 1998). In this project, the students should develop competencies of several curricular units of the semester in an integrated, multidisciplinary way. Moreover, even without the knowledge of some important subjects such as resistance of materials, fluid mechanics and construction materials, which wil be studied within the next semesters, the students create the perception of how things work. They test solutions, even empirically, that will later meet in specific disciplines, facing them with more confidence and with some knowledge of the content. Among other, the project has two objectives: apply curricular units' contents in the proposed task and contribute to a deeper comprehension of such contents.

Within this context the present work is inserted, since an evaluation of an "Energy Power Plant" PSA was performed through the assessment of the student's knowledge before the start of the activity and after its conclusion. This follow up was done using an intuitive questionnaire related to the physical concepts involved on the activity. Through the statistical analysis of the questionnaires applied on each moment (before and after), it was possible to assess the student's knowledge gain and to map the several learning difficulties of some of the physical concepts presented at the classroom.

## 2. Materials and Methods

There are some techniques that can be used for measuring ongoing students' learning, mainly inside the classroom (Angelo and Cross 1993). In the present study, the technique chosen for measuring the students learning was easy to implement without creating any difficulty to students or teachers, even for a practical activity that happens outside the classroom, as is the case of PSA.

A physics teachers group developed several questions relating the physical concepts involved on the activity. This intuitive test was applied before the practical activity of the energy power plant in order to reflect the background knowledge of students to the topic covered in the proposal. The questionnaire is shown in the figures below:

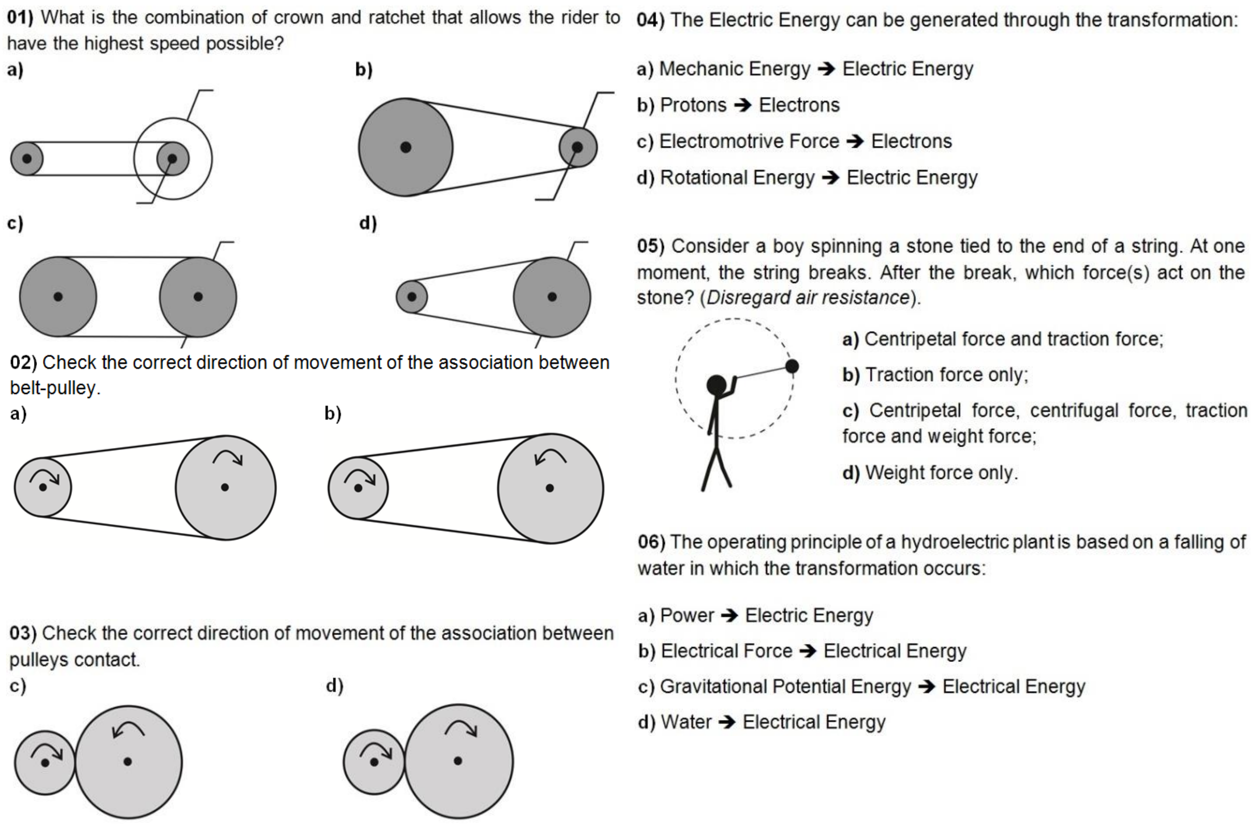


Figure 1: The proposed questionnaire

The student's knowledge gain can be used as a quality characteristic for statistical process control (Angelo and Cross 1993). The students answered six objective type questions, once prior the PSA and the again after the PSA evaluation. For this work, up to 444 questionnaire results were collected, regarding engineering students in the first semester of their under graduate course and, at least 327 test results about students in the second/third semester. This data were collected and analyzed concerning outside classroom physics teaching and learning outcomes in engineering education.

For better understanding a schematic illustration of the energy power plant project is presented:

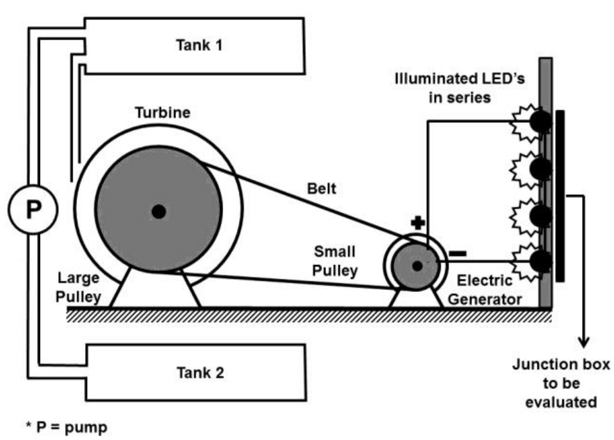


Figure 2: Schematic illustration of the energy power plant

## 3. Results and Discussion

In order to evaluate the student's knowledge improvement due to the activity, the rate of correct answered questions before and after the conclusion of the PSA were compared. The difference on the percentage of correct answers at the two moments express the knowledge improvement achieved by the student himself through the development of the PSA. Table 1 presents the percentage of correct answers before and after the PSA obtained with the first semester of all the engineering courses combined, while figure 3 presents a bar plot of Table 1's percentages, but for each question separately.

Table 1: Percentage of correct answers before and after the PSA by engineering students in the first semester.

| Percentage of Correct Answers_1º Semester | | |
|---|---|---|
| Question Number | Before PSA (%) | After PSA (%) |
| 1 | 65.3 | 70.6 |
| 2 | 80.6 | 82.8 |
| 3 | 31.5 | 35.1 |
| 4 | 59.5 | 65.5 |
| 5 | 30.9 | 27.2 |
| 6 | 44.1 | 48.9 |
| Overall | 51.9 | 55.0 |

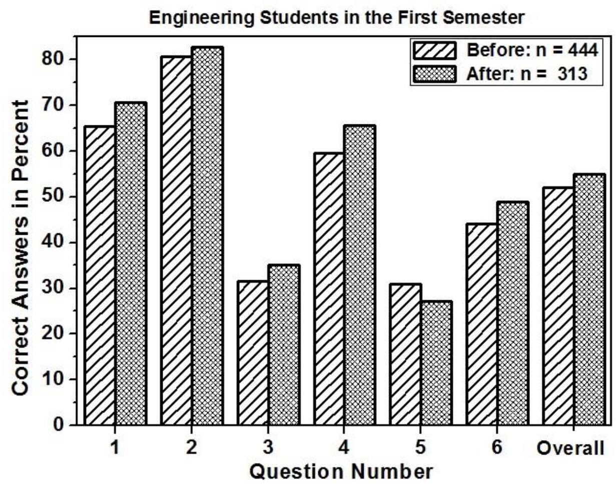


Figure 3: Histogram of correct answers percentage before and after the PSA by engineering students in the first semester.

By the graph on figure 2, it can be clearly seen a significant raise in the student's knowledge related to the proposed subject. Except question No. 5, the correct answers rate for the questions 1, 2, 3, 4 and 6 raised 5.3%, 2.2%, 6% e 4.8%, respectively. It is important to remember that these first semester students had not had physical classes that discussed the concepts involved in the PSA. Reiterating what has been proposed by Freire (2011) in the constructivist methodology, the use of background knowledge by the student must be stimulated so that they build a line of reasoning through critical reflection based on their own experimentations - all developed within a group, to promote also the sharing of experiences among the student-student pairs. Regarding question 5, a low percentage of correct answers and even a worsening on the results occurred. This was expected since the students have not had a specific discipline dealing with force and movement. Gomes (2008) concluded on his work that the majority of students that join engineering courses have the same behavior in regards to force and movement concepts, which is necessary for the construction of their scientific knowledge. In face of this discussion, the professors should use this transition to introduce and explain Newtonian physics, which is primordial in building a solid base to the next disciplines of the engineering courses, on both basic and specific levels.

Table 2 provides data of percentage of correct answers before and after PSA for the second and third semesters of all engineering courses. Figure 4 presents a bar plot of Table 2 percentages, but for each question.

Table 2: Percentage of correct answers before and after the PSA by engineering students in the second/third semester.

| Percentage of Correct Answers_2º/3º Semester | | |
|---|---|---|
| Question Number | Before PSA (%) | After PSA (%) |
| 1 | 73.7 | 67.1 |
| 2 | 80.7 | 82.6 |
| 3 | 53.2 | 58.4 |
| 4 | 71.0 | 71.2 |
| 5 | 37.0 | 42.6 |
| 6 | 55.7 | 59.3 |
| Overall | 61.9 | 63.5 |

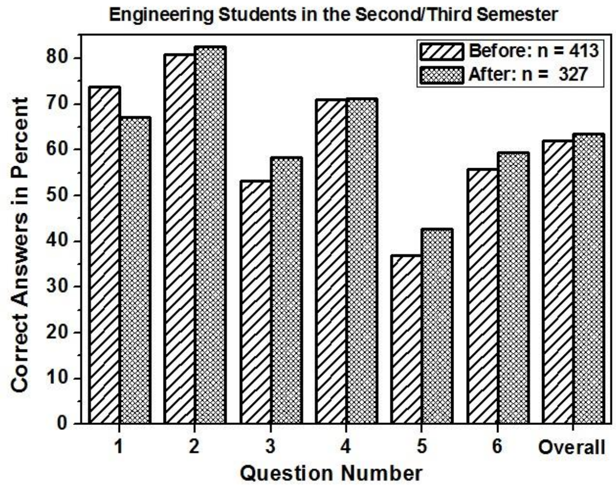


Figure 4: Histogram of correct answers before and after the PSA by engineering students in the second/third semester.

By the graph on figure 4, it is possible to observe an improvement in the learning of the 2nd and 3rd semester students. Except question No. 1, all other questions (2, 3, 4, 5 and 6) presented a raise in the number of correct answers of 1.9%, 5.2%, 0.2%, 5.6% and 3.6%, respectively. Figure 5 compares the results of classes from 1st, 2nd and 3rd semesters.

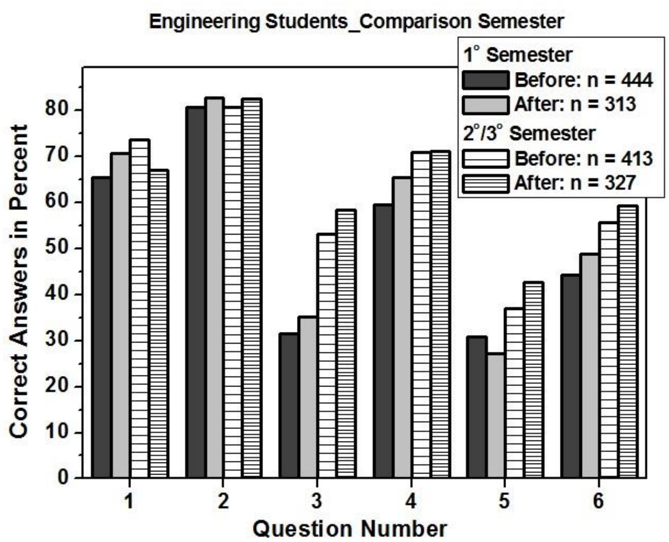


Figure 5: Comparison of quantitative learning among engineering students in the first and second/third semesters, before and after PSA project.

On the overall proportion of correct answers, the 1st semester students had a higher improvement (3.1%) in comparison to the 2nd and 3rd semester students (1.6%). Nevertheless, it should be noted that the starting knowledge level (before PSA) of the 2nd and 3rd semester students is higher than the 1st semester students, since they already have some theoretical basis from the first physics courses. Aiming to improve the results for all three semesters, on a future study, constructivist methodologies will be more widely applied in order to prevent students from playing a passive role by giving them more freedom instead and, thus, inserting them on the constant process of building his own knowledge day-by-day on the classroom.

Since the 1st semester students have not had specific physics disciplines to discuss the concepts learned with the PSA, their previous knowledge was more used instead to build their scientific knowledge – as observed on the correct answers percentage before and after the PSA. With the purpose of significant and continuous learning, activities that link theory and practice must be more widely applied within the classroom, through questionings that bring the abstract world of theory to the student's reality.

Finally, the graph in figure 6 illustrates a comparison among students of 1st, 2nd and 3rd semesters divided by specific engineering fields. By the result, it becomes evident that the percentage of correct answers varies according to the different student profile at each specific engineering course.

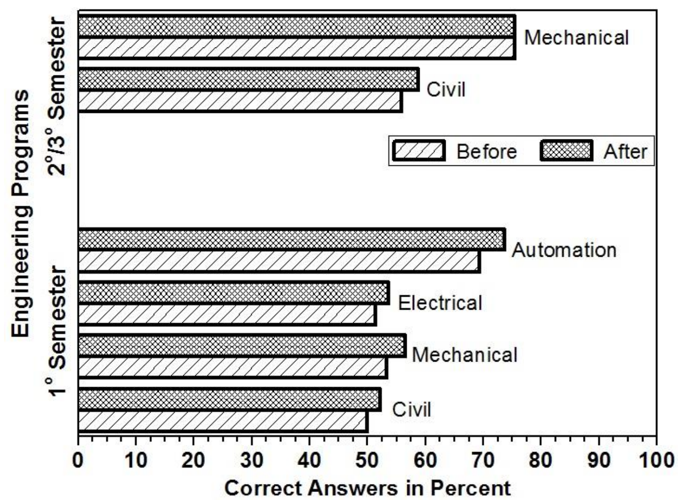


Figure 6: Comparison of quantitative learning for different Engineering programs and among engineering students in the first and second/third semesters, before and after PSA project.

## Conclusions

The methodology described in this paper "learning through practice" of surveying engineering education. The methodological development showed learning based on the tasks carried out by groups of students. With the adoption of this methodology the students developed several competencies: knowledge, skills and attitudes.

On the overall proportion of correct answers, the 1st semester students showed a higher improvement in comparison to the 2nd and 3rd semester students. Nevertheless, it should be noted that the starting knowledge level (before PSA) of the 2nd and 3rd semester students is higher than the 1st semester students, since they already have some theoretical basis from the first physics courses. In addition to this, a comparison between students of 1st, 2nd and 3rd semesters divided by specific engineering fields evidenced that the percentage of correct answers varies according to the different student profile among each specific engineering course. Finally, the statistic methodology used to evaluate surveying engineering education showed the knowledge gain by students where the practical aspect is an important component.

The GruPEFE has been working for only two years at Paulista University (UNIP) analyzing a series of "Practice-Supervised Activities" (PSA). Even in this short period of work, the obtained results by proposed methodology were satisfactory. In the future, the GruPEFE will perform a more in depth analysis of some aspects related to the methodology and the education system used.

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