# Project-Based Learning: a strategy for teaching integral differential calculus for engineering students in a school in Brazil

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## Abstract

*This paper presents an introduction to Project-Based Learning (PBL), which is an active methodology that aims to facilitate the learning of technical knowledge and encourages the introduction of active methods in engineering teaching. The PBL approach in the discipline of Calculus I contemplated the elaboration of a project developed by the students to analyze important characteristics in the production of cylindrical cans. Calculation concepts were applied and the students developed a model in order to optimize the dimensions of the can and take advantage of the plates used. The aim of this study was proposing a* *challenge to students with real problems and promoting transdisciplinary knowledge, by means of PBL model. It was developed at the Engineering School of Lorena, Brazil (University of São Paulo – EEL-USP). Concepts of application of derivatives and Fermat's theorem were used, learned in the discipline of Differential and Integral Calculus, in order to obtain the maximum and minimum values of an established function which relates the dimensions of the can and the amount of material needed. The dimensions obtained theoretically proved to be close to the real values found in cans available on the market. After analyzing the resistance to corrosion, the cost, the decomposition time and the mechanical resistance, it was concluded that the most appropriate material for the production of cans was the tinplate. In this context, teaching with Project Based Learning methodologies may contribute to innovative teaching practices in the training of engineering professionals, overcoming the limitations of traditional teaching methods.*

**Keywords:** Can design; Project-Based Learning; Sustainable cans; Cylindrical optimization

## 1. Introduction

Themes related to the generation of waste are increasingly evident in contemporary society, especially when it comes to packaging made of metallic materials. Thus, the theme of sustainability has become the guideline of industries, which seek to reduce the amount of raw materials used, aiming at lower costs and environmental preservation.

In the area of packaging, the materials used should be properly studied to avoid product contamination, reduce environmental impacts and minimize costs, since if a material does not have low value, companies do not adhere to the idea. On the environment side, it is also necessary to take into account the Sustainable Development 12 and 15 (SDG) goals where the first aims to achieve sustainable management and resource use in a more eficiente way. The second is associated in the preservation and recovery of the terrestrial ecosystem [1].

Even though Brazil is the 12th among the countries that research the most, it is considered the country that recycles the most aluminum cans in the world [2]. That great amount recycled is important because it decreases the waste discarded in the nature, besides making the industries save in the purchse of raw material, considering that the recycled product has lower cost.

The cans are cylindrical in shape due to several factors, such as: effectiveness in welding; need to maximize their volume and minimize the amount of worn material; demand of increased resistance to mechanical shocks and indispensability of a uniform internal pressure [3]. In the literature, Santos and co-workers [4] presented the calculations about the ideal values and geometries in order to optimize the production of cans from the tinplates. Thus, it is analyzed that the smaller the area of material used, the smaller the surface susceptible to corrosion [5]. In addition to calculations, materials are also studied for sustainable purposes [6].

In turn, the use of alternative materials of low cost and minimal environmental impact is widely studied in order to promote sustainable marketing for industries. Thus, it is possible to obtain a more significant profit, considering that environmentally friendly products have greater market appeal [7]. In Brazil, the most used sustainable materials in cans are tinplates, which is derived from steel, aluminum, which is derived from bauxite [8]. As an advantage, Brazil is one of the largest bauxite producers in the world. Being in 4th place in 2018 [9].

The teaching of engineering in Brazil has been the subject of many discussions focusing primarily curricular organizations, with less emphasis on learning methodologies for the development of professional competencies. One of the problem that concern many engineering courses is the lack of motivation of the students in relation to the type of education they receive, with consequences on the student performance and dropout rates. The current research shows the results, which were obtained by the coordination between professor, students and master matters in the year 2019.

Several studies emphasize the insertion of new learning tools and activities (e.g. playing and learning using simulations, experimental cases and learning with gamification) using information and communication technology. Therefore, students must learn materials on their own with minimum guidance by professor [10]. This methodology had good results in the last decades. Within this context, Universities introduce project-based learning into their curricula in order to improve the engineering students' skills and curricula [11–14].

In this particular case, this study enabled students of the Chemical Engineering course of the Lorena School of Engineering EEL-USP could begin the topics of the discipline of Differential and Integral Calculus by developing activities based on sustainable projects related to sustainable cylindrical packaging. These activities were applied in the classroom, as learning strategies and enabled students to progress with a study plan and develop complete research papers that were applied in everyday situations. Project-based learning enables students to acquire knowledge and skills through the development of projects that meet the needs of contemporary society.

The aim of this work is to present the project-based learning developed at the Lorena School of Engineering – University of São Paulo through the discipline of Differential and Integral Calculus and enable students to work with sustainable projects with the application of the contents presented in the classroom, overcoming many limitations of traditional teaching models.

## 2. Contextualization of the global importance of the theme

Sustainable cans is a subject whose relevance is becoming increasingly important. The intensification of this subject is observed in Figure 1, which presents the number of articles published per year with the theme "*Sustainable Cans*". It is observed a significant increase in the scientific importance of the theme over the years (2015 – 2020), emphasizing the special attention of researchers to this area of research and development.

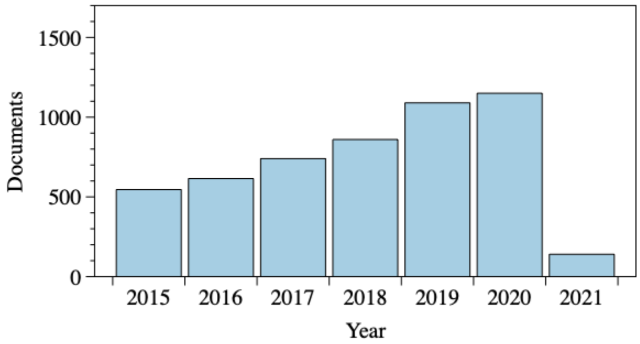


Figure 1. Number of publications per year. Source: Scopus for search "Sustainable Cans" in all subject area. Period: 2015 – 2020 (Year 2021: from January to May).

Figure 2 shows, in descending order, the number of publications of universities on this subject, highlighting the relevance of this issue in the institutions of the most diverse countries of the world. The University of São Paulo appears in eighth place, with almost 500 publications on the subject, emphasizing the importance of the theme in Brazil.

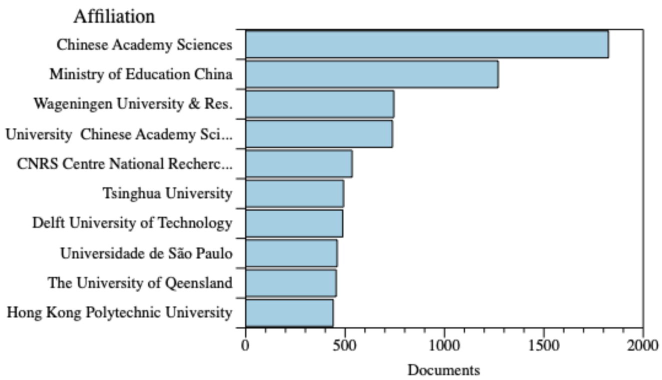


Figure 2. Number of documents published by institution between 2015 and 2020. Source: Scopus.

From the data analyzed, it is concluded that the study of the optimization of cylindrical packaging is directly related to the financial resources of the country and the institution, in view of the fact that research on this subject requires financial investment and direct contact with the industry.

## 3. Teaching learning process

Engineering education follows a traditional perspective in the training of engineers with deductive teaching approaches, which relate the introduction of a subject by the professor in the classroom, on the principles used in the derivation of mathematical models and their applications. The practice is provided to students through similar applications and derivations through extra exercises and, in the end, their skills are tested in the execution of the same set of tasks and tests. Within this context, little emphasis is given to mathematical models to be applied in the real world, that is, emphasizing their importance for the future profession [15].

According to the report of the World Economic Forum [16], entitled The Future of Jobs, it points to changes in the industrial hiring scenario, according to the pandemic, which links to a remote and hybrid workforce for professionals. According to the Institute of Applied Economic Research [17], the Brazilian market offers opportunities for professionals who meet the needs of the future such as: sustainable engineering, multidisciplinary professionals, use of virtual resources in projects, skills in communication and professional self-management.

Due to this evolution of the professional's profile, the conventional teaching method used in many universities is not considered efficient for preparing students who are finishing their undergraduate degree [18]. Therefore, universities linked to engineering courses seek new ways to develop skills in newly graduated professionals. One of the forms is the implementation of project-based learning, which allows students to participate in theoretical classes [19].

Project-based learning is an active methodology that consists of developing projects based on real problems in order to develop knowledge and skills that are passed on in theory. By dealing with a student-centered method, it emphasizes learning and allows interaction between peers, seeking information, formulating hypotheses and making decisions. This involvement in the search for solutions to the problem enables students to become responsible for their own learning [15].

This learning methodology admits work sequences that may vary according to the level and type of teaching, with the area of knowledge and with the objectives that one wants to achieve. In general, it includes the stages presented in Figure 3.

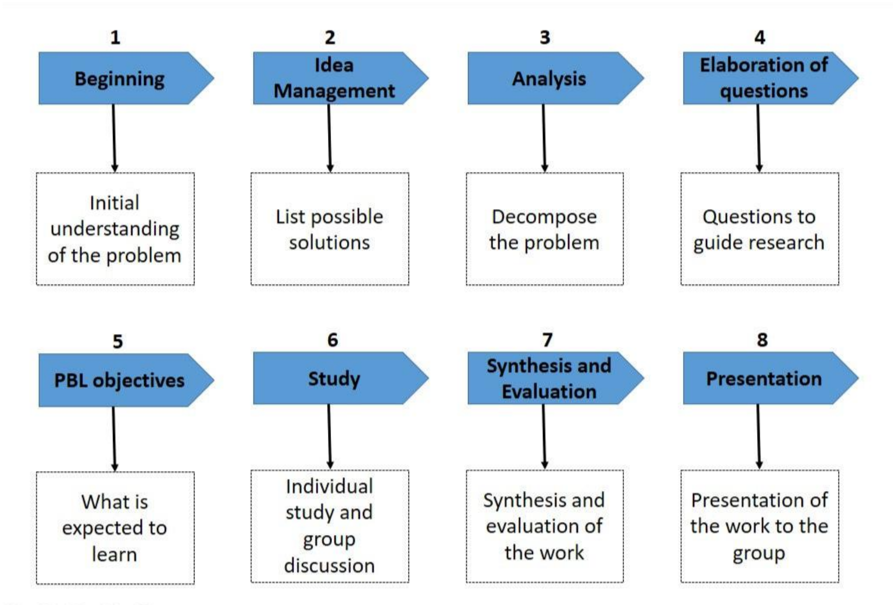


Figure 3 Steps in the implementation of project-based learning. Source: Araújo [20].

## 4. Methodology

The project considered several important aspects, involving the use of sheet metal to be used by the industry. Moreover, it has also been studied the dimensioning of the cylinders (considering the amount of material used and the cutting length) and the choice of material.

Initially, it was determined which shape of the metal sheet is more profitable, in order to cause less waste. Disc formats were compared from squares or hexagons, based on the waste of each cut. With this factor determined, a ratio between $h$ and $r$ was calculated, through the derivation of the surface area formula in relation to the radius, in which h was replaced by the equation $h = \frac{V}{\pi r^2}$, in which the volume is constant, since it is related to the amount of material expended. According to Fermat's theorem, which provides the point of maximum or local minimum, the minimization of this area was obtained. Through the Second Derivative Test it was observed that the point was of local minimum. It was based on a cost ratio as a function of variables $h$ and $r$, which is $C(r, h) = 4\sqrt{3}r^2 + 2\pi rh + k(4\pi r + h)$. From this equation, it was proposed to minimize the cost and for this $h$ was replaced by a function that related the volume and radius. Then the first derivative was calculated in relation to $r$, based on a constant volume. With the first derivative determined, it was possible to find the minimization of the cost. From the Second Derivative Test, it was found that the point corresponded to a local minimum point. With these calculations, a relationship between volume and $k$ was found, which represents the inverse of length, as a function of $h$ and $r$.

On the packaging, the height with the leftover caused by the folding of the disc (cover), the height without the leftover and the radius were measured. Then, the volume was determined for each of the measures, taking as basis the height without the surplus and also the ratio between $h$ and $r$.

The amount of material used to obtain cylindrical can covers from square-cut discs was analyzed, presented in Figure 4 and discs from hexagons, Figure 5. This analysis aims to reduce the wasted material and the cost of packaging.

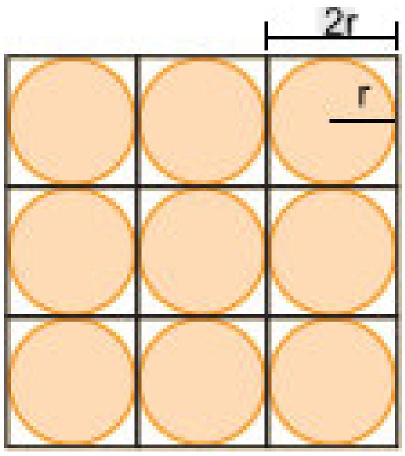


Figure 4. Discs made from squares. Source: Stewart [3].

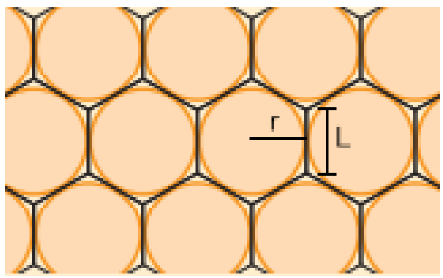


Figure 5. Discs made from hexagons. Source: Stewart [3].

For the waste ($D_1$) of the discs from squares, equation 1 was considered:

$D_1 = A_{square} - A_{disc} \therefore D_1 = 4r^2 - \pi r^2 \therefore D_1 = r^2(4-\pi)$ (1)

For the waste ($D_2$) of the discs from hexagons, equation 2 was considered:

$D_2 = A_{hexagon} - A_{disc} \therefore D_2 = 2\sqrt{3}r^2 \therefore D_2 = r^2\left(2\sqrt{3}-\pi\right)$ (2)

Analyzing the two equations ($D_1$) and ($D_2$), and obtaining a fraction based on them, we have $\frac{D_1}{D_2} = \frac{4-\pi}{2\sqrt{3}-p}$ which results in a numerical value, since the radius of the disc is the same in both cases, according to equation 3

$\frac{D_1}{D_2} \approx 2.66$ (3)

According to equation 3, it was observed that material waste for the production of the discs is lower when obtained from hexagons. Therefore, it is more profitable for a company to cut the discs from hexagons.

In this study, the optimization process was used to minimize the surface area of the cylinder, decreasing the expended material. Then, $A_S$ represents the surface area of the cylinder, $r$ the radius of the base, $V$ the volume of the cylinder and $h$ the height. Equation 4 represents the surface area, equation 5 the cylinder volume and equation 6 the height substitution in equation 4:

$A_s = 2\pi rh + 2\pi r^2$ (4)

$V = \pi r^2 h \therefore h = \frac{V}{\pi r^2}$ (5)

$A_s = \frac{2V}{r} + 2\pi r^2$ (6)

The optimization method made it possible to derive equation 6 to find the minimum surface area in a given volume. It is obtained from $\frac{dAs}{dr} = \frac{4\pi r^3 - 2V}{r^2}$ and to find the minimum surface area, from Fermat's Theorem, to determine the maximum and local minimum of a function, equaling its first derivative to zero [3]. Whereas $V = 2\pi r^3$ and substituting in equation 5 the ratio between $h$ and $r$ (equation 7) was determined:

$\frac{h}{r} = 2$ (7)

Through the Second Derivative Theorem, if $f'(c) = 0$ and $f''(c) > 0$ then c is a local minimum of $f$ , and if $f'' < 0$ then c is local maximum of $f$ [3].

In this case, the second derivative $\frac{d^2As}{dr^2} = \frac{4\pi r^4 + 4Vr}{r^4}$ will be positive.

Equation 8 relates the cost from cutting the discs (hexagons) to the dimensions of the material, where $k$ represents the inverse of the length and it is associated with the cost per unit of metal area:

$C(r,h) = 4\sqrt{3}r^2 + 2\pi rh + k(4\pi r + h)$ (8)

To minimize the cost, equation 5 was replaced in equation 8, resulting in equation 9:

$C(r) = 4\sqrt{3}r^2 + \frac{2V}{r} + k\left(4\pi r + \frac{V}{\pi r^2}\right)$ (9)

From the calculation of the first derivative as a function of the radius in equation 9, equation 10 is determined:

$$C'(r) = 8\sqrt{3}r - \frac{2V}{r^2} + k\left(4\pi - \frac{2V}{\pi r^3}\right) \quad (10)$$

In equation 10 the minimum cost was determined, through the second derivative, $\frac{d^2C}{dr^2} = 8\sqrt{3} + \frac{4V}{r^3} + \frac{6Vk}{\pi r^4}$, a local minimum point was observed. With adjustments to equation 10 and equalling it to zero, $\frac{4\pi kr^3}{r^3} - \frac{2Vk}{\pi r^3} + \frac{8\sqrt{3}r^4}{r^3} - \frac{2Vr}{r^3} = 0$ was obtained, simplified by equation 5 with the substitution of $r = \sqrt[3]{\frac{Vr}{\pi h}}$, equation 11 was obtained:

$$2\pi kr^3 - \frac{Vk}{\pi} + 4\sqrt{3}r^4 - Vr = 0 \quad (11)$$

Replacing the expressions from equation 5 in equation 11, equation 12 is obtained:

$$2\pi kr^3 - \frac{Vk}{\pi} + 4\sqrt{3}r^3\sqrt[3]{\frac{Vr}{\pi h}} - V\sqrt[3]{\frac{Vr}{\pi h}} = 0 \quad (12)$$

After dividing equation 12 by $k$, equation 13 is given:

$$\frac{V\sqrt[3]{V}}{k}\sqrt[3]{\frac{r}{\pi h}} - \frac{4\sqrt{3}r^3\sqrt[3]{V}}{k}\sqrt[3]{\frac{r}{\pi h}} = 2\pi r^3 - \frac{V}{\pi} \quad (13)$$

Rearranging equation 13 and considering the term $\frac{\sqrt[3]{V}}{k}$ in evidence, equation 14 is determined:

$$\frac{\sqrt[3]{V}}{k} = \sqrt[3]{\frac{\pi h}{r}} \cdot \frac{2\pi - \frac{h}{r}}{\frac{\pi h}{r} - 4\sqrt{3}} \quad (14)$$

Considering the relationship found between $h$ and $r$ in equation 7, it is known that for the maximum volume with the smallest surface area, the height will be corresponding to $h = 2r$ and its length will be equal to $2r$. The perimeter of this rectangle is represented by equation 15:

$$P = 2h + 4r \quad (15)$$

In equation 15, substituting the circumference value corresponding to 36 cm and the height by $2r$, it is found that $h = 9$ cm and $r = 4.5$ cm. $V = 572.56$ cm$^3$ was determined by equation 5.

## 5. Results and Discussion

### *5.1. Sizing of cans*

Table 1 shows the data obtained from the measurements of cans of different products, as well as the ratio between $h$ and $r$. It was observed that the ratios between $h$ and $r$ were close to the theoretically obtained, considering the height used for the ratio without the surplus.

Table 1. analysis of cans found in the market.

| Model | Height without spare (cm) | Height with spare (cm) | Radius (cm) | Volume ($cm^3$) | $h/r$ |
|---|---|---|---|---|---|
| 1 | 7.70 | 8.30 | 3.70 | 331.16 | 2.08 |
| 2 | 11.10 | 11.70 | 5.10 | 907.01 | 2.18 |
| 3 | 7.70 | 8.30 | 3.70 | 331.16 | 2.08 |
| 4 | 10.30 | 10.80 | 3.73 | 450.20 | 2.76 |
| 5 | 7.70 | 8.35 | 3.70 | 331.16 | 2.08 |
| 6 | 5.20 | 5.70 | 3.05 | 151.97 | 1.70 |
| 7 | 11.20 | 11.80 | 5.05 | 897.33 | 2.22 |
| 8 | 7.40 | 8.10 | 3.75 | 326.92 | 1.97 |
| 9 | 11.20 | 11.80 | 5.05 | 897.33 | 2.22 |
| 10 | 9.80 | 10.35 | 5.05 | 785.16 | 1.94 |

According to the results found and to the research analysis, it has been verified that the cylinder is the best option to maximize the volume, decreasing the waste material area. Furthermore, it's possible to notice the similarities between the obtained values from Stewart and the methodology found numbers, proving the study convergence

### *5.2. Choice of material for the manufacture of cans*

In search of the most economically viable metal material and with less environmental impact, two types of raw material were analyzed for the cans studied: Tin foil and aluminum foil. In each material, the following aspects were pointed out: corrosion resistance, environmental impact, mechanical resistance and price [2]. The different characteristics of two analyzed materials are found in Table 2.

Table 2. Characteristics of the materials used in the manufacture of cans.

| | Tin Foil | Aluminum Foil |
|---|---|---|
| Corrosion resistance | High | Low |
| Cost | Average | High |
| Decomposition time | 10 years | 100 to 500 years |
| Mechanical resistance | High | Low |

The tin foil, the most used material in the production of canned products, consists basically of a steel plate (low carbon iron alloy) coated with tin. The layer composed of iron and tin alloy gives the package greater resistance to acid corrosion, while the steel layer increases resistance to mechanical shocks. In turn, the oil layer minimizes the damage caused by abrasion [21]. Basically, the composition of the tin foil unites the mechanical strength of the steel with the high corrosion resistance and the weldability of the tin.

Previously, due to the absence of improved production techniques of the tin foil, there was inadequate coating of tin, generating contamination of the product and, consequently, of the environment. Currently, this coating process is avoided with the aid of improved tin deposition processes by an electrochemical treatment.

In turn, aluminum foil has high oxidation resistance, besides being easy to shape. However, its production requires a lot of energy, making the cost of this material higher. To avoid contamination, the element is used in the form of alloys with purity in the order of 98.0% to 99.8%, which improves its mechanical properties. In addition, packaging is coated with an organic varnish in order to minimize the interaction of the metal with the food.

With respect to the decomposition time, steel cans (tin foil) are decomposed in about 10 years. Aluminum cans take between 200 and 500 years to decompose [22].

In this way, it was evidenced in this study that the tinplates is the most suitable ferrous material for the manufacture of cans. Due to its characteristics it can be used in numerous types of packaging, in various shapes and sizes, offering resistance to corrosion due to its surface properties. Steel-based packaging (tinplate) is sorted by magnet systems and delivered to the metallurgical industries to be re-melted. Through this process it is possible to remove up to 90% of the ferrous metal existing in the garbage.

The reuse rate of these cans is also highlighted, which reveals the efficiency of the recycling process by the Brazilian industry. This practice promotes the reduction up to 95% of greenhouse gas emissions into the atmosphere.

## 5. Conclusion

Based on the study carried out, the modeling developed, especially in cylindrical cans, provided the construction of models that are used by several industries, due to the minimization of materials used. With the reduction in the cost of packaging, the companies increased their profits.

Thus, from the modeling obtained $\frac{\sqrt[3]{V}}{k} = \sqrt[3]{\frac{\pi h}{r}}.\frac{2\pi - h/r}{\pi h/r - 4\sqrt[2]{3}}$ the ratios were determined to maximize the volume of the can and minimize the amount of material used that made it possible to reduce the cost of the can. Besides, for the analysis of the materials, it was seen that the tin foil was the most suitable one, due to the low cost, the high mechanical and corrosive resistance, besides the low decomposition time, becoming more sustainable.

Project-Based Learning allowed Engineering students to experience deeply significant learning situations related to everyday experiences. This way it will be possible to create a generation of professionals who will be able to face new problems and conduct innovative Engineering projects in the national or international labor market.

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