A proposition to teach engineering projects using Problem-based Learning (PBL) concepts

Uma proposta para ensinar projetos de engenharia usando conceitos de Aprendizagem Baseada em Problemas (PBL)

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ABSTRACT
This article shows the design of a mechanical engineering project using problem-based learning concepts. The work shows the complexity of the teaching-learning process of a complex problem such as developing, simulating, and testing a prototype of a piezoresistive pressure sensor. This type of problem is typical in theoretical-practical classes involving different concepts learned during an undergraduate course. The cognitive structure may or may not be influenced by the presentation of ideas and methods for organizing the content and executing the desired project. Using a pressure sensor project made it possible to develop the concepts of learning models by applying the idea of project-based learning (PBL). The main results obtained were the product design topology, operating concepts of a sensor device, computer-aided design projects, analysis of simulation results and assembly, and mechanical prototyping concepts, involving different materials for machining and product encapsulation.

Keywords: Problem-based Learning, engineering project, teaching learning.

RESUMO
Este artigo mostra a elaboração de um projeto de engenharia mecânica usando conceitos de aprendizagem baseada em problemas. O trabalho mostra a complexidade do processo de ensino-aprendizagem de um problema complexo...
como desenvolver, simular e testar um protótipo de sensor de pressão piezoresistivo. Este tipo de problema é típico de aulas teórico-práticas envolvendo diferentes conceitos aprendidos durante um curso de graduação. A estrutura cognitiva pode ou não ser influenciada pela apresentação de ideias e métodos de organização do conteúdo e execução do projeto desejado. A utilização de um projeto de sensor de pressão possibilitou desenvolver os conceitos de modelos de aprendizagem aplicando a ideia de aprendizagem baseada em projetos (PBL). Os principais resultados obtidos foram a topologia de projeto do produto, conceitos de funcionamento de um dispositivo sensor, projetos de design auxiliado por computador, análise de resultados de simulação e montagem, e conceitos de prototipagem mecânica, envolvendo diferentes materiais para usinagem e encapsulamento do produto.


1 INTRODUCTION

Industry 4.0 has presented many improvements in manufacturing processes, particularly in the automobile sector. This is due, in part, to teamwork and the flexibility of the processes of learning new techniques and handling modern machines and equipment to produce parts, equipment and accessories.

In this article it is proposed the design of a pressure sensor based on materials and procedures of low cost and environmental impact. The proposition and solution of the problem has the initial focus based on the concepts of mechanical tests, standardized procedures that comprise tests, calculations, graphs, and queries to tables, all in accordance with technical standards. Performing a test consists of submitting an already manufactured object or a material that will be processed, industrially, to situations that simulate the mechanical stresses that they will suffer in the real conditions of use, reaching extreme limits of load request (Souza, 1984). These concepts involve different knowledge of the engineering area that must be employed to give solution to the problem or object of study starting, for example, with a CAD project – Computer Aided Design and, subsequently, following the other planned steps.

According to (Maia, do Carmo & Pontes, 2020) active methodologies have the potential to overcome many of the limitations brought by students to the university, being defined as strategies capable of developing the participatory
posture, positioning it at the center of educational actions, to encourage its independence in the conception of knowledge. The strategies outlined by the teacher aim to provide the student with an understanding and solution of the propositions presented during the discussions in the classroom or even in the laboratory. An approach based on projects (project-based learning – PBL) allows educators engage students through challenges and investigation.

In the different fields of technology and those referring to the construction of machines and structures are closely linked to materials and their properties. Mechanical properties, for example, refer to the way materials react to external mechanical stresses, showing deformation or rupture. There are several criteria for classifying mechanical tests considering destructive and non-destructive type tests. Among some of these tests, there are the visual, penetrating liquid, magnetic particles, ultrasound and industrial radiography and stress and mechanical deformation.

In engineering, the concept of research methodology for PDP - Product Development Project is used, which can be adapted to develop or perfect parts, machinery, and equipment. Thus, it is possible to give a greater emphasis on the phases of the project in which they really matter for the improvement of products (Pahl, Beitez, Feldhusen & Grote, 2007), in the specific case of study proposed here, development of packages for pressure sensing devices.

Therefore, focusing on the student means encouraging them to develop skills and competencies allied to the theoretical and practical knowledge provided in the curricular components of their course so that they have a better understanding, reflection and questioning of the contents already studied and the new concepts to be apprehended and that, many times, are interconnected with the different areas of systematized knowledge.

The relationship between making think and learning, maintained by the teacher and the student is a concept that involves learning based on problems that are the daily doing of a future professional, especially mechanical engineering.

Figure 1 illustrates the process of developing a product involving all the steps from the process of generating the idea to the possibility of launching the
product in the market (Romano, 2013). These concepts can be applied to original products, improved products or to adaptation of products found in the market.

Figure 1: Product typology versus duration of project activities.

Source: The Authors

The informational project aims to establish the product design specifications, initiating research of information on the topic related to the project, with the establishment of its requirements for the development of the encapsulation of piezoresistive pressure sensors.

In the conceptual design phase, activities will be carried out aimed only at confirming the design of the product, which also reduces the design time of the pressure sensing device.

In the preliminary design phase will be given the final form of the conception described in the conceptual design defining the material to be used and the geometric shape given to the intended encapsulation. In this step, CAD design software is used to create each necessary component, as well as the assembly of each part that will form the final assembly of the desired sensor device.

In the detailed design phase is defined the form of the design of sensor device, performing a computer simulation using the concepts of Finite Element Analysis (FEA), aiming to understand the physical concepts about mechanical
strength, as well as choose the best place where to fix the piezoresistive sensor that will read the mechanical deformation. The pressure sensor membrane will transform the measurements into an electrical voltage signal so that the results can be interpreted and shown to the user.

2 MATERIALS AND METHODS

The design of pressure sensing devices is directly related to the working pressure range, materials that will be used for the encapsulation, processes in which the materials of each component will be manufactured, obtaining each encapsulation design and the geometric shape of the sensing device that will be designed. These concepts are worked according to the theoretical and practical knowledge provided in the curricular components of each course. The teaching-learning process using the concepts of PBL are somewhat complex and involve multidisciplinary concepts and methodology that aims to motivate the student to learn more actively, aiming to solve engineering problems, often also complex. This way of teaching and learning stimulates the curiosity and interest of the student in research, consolidating their knowledge in a practical and flexible mode (Maia, Carmo & Pontes, 2020).

Figure 2 illustrates the main engineering design concepts for the pressure sensor involving the possible desired steps to obtain a functional product.
Figure 2: Illustration of engineering design to develop ABP concepts.

The pressure sensing device is designed and machined from Acetal type polymer with an elastic modulus of 2.9 MPa and Poisson’s ratio 0.35, composed of three main parts, as shown in Figure 2. Connection (1) serves as an oil inlet, where pressure is exerted, as there is a hole. The Cover (2) allows the passage of the electrical cable of the piezoresistive sensor, and both form the polymeric casing that isolates and protects the place where the sensor will be fixed next to the Diaphragm (3) made of 5182-H34 aluminum.

The illustration in Figure 2 also highlights the physical concepts for design, the concepts for CAD design and a metallic assembly with a pressure gauge for functional tests.

3 RESULTS AND DISCUSSIONS

After the CAD project, mathematical analyzes of the von Mises mechanical stresses were carried out, as illustrated in Figure 3. Figure 3 (a) illustrates the complete assembly. Figure 3 (b) the gluing of a strain gauge and Figure 3 (c) the gluing of two piezoresistive sensing elements.
Figure 3: Mathematical simulation showing the distribution of mechanical stresses and appearance of the assembly.

Figure 3 shows that in the central region of the polymeric membrane the supported nodal mechanical stress would be on the order of 288 MPa. The test pressure used was 0.7 MPa (7Bar) as the design objective was for use with low pressure pneumatic systems. The membrane considered for fixing the piezoresistors (strain gauges), in this simulation, is 0.185 mm. In the computational analysis, a maximum mechanical deformation of the order of 0.283 % increase was obtained, in the center of the membrane, in relation to the useful radius of the membrane and the FOS - safety coefficient obtained represents 0.833 (calculated by the relationship between the tension of material flow (240 MPa) by maximum von Mises stress with maximum mechanical displacement of the radius of 0.1303 mm.

The first analysis carried out to teach CAD design and interpret results from computer simulations involves multidisciplinary concepts that are often isolated by the student and are not reviewed or used when it is necessary to carry out a complex engineering project.
Teaching using PBL requires that many of the details of equipment or device designs are highlighted by the teacher. Thus, Figure 4 shows an open view of the other components of the project and an experimental test bench for pneumatic pressure.

Figure 4: (a) Exploded view of the acetal sensor with Aluminum membrane and screwed and (b) experimental arrangement with compressed air source, dial indicator and pressure gauges.

In summary, a teaching and learning process based on PBL with active methodology in many cases requires very effective involvement from the student and the educator (Silva, L. G., Lima, B. M., & Dias, Lisete Funari, 2023). Second, (Setemen, K., Sudirtha, G., & Widiana, Wayan, 2023) e-learning and PBL concepts can increase the learning performance of students, measured by the achievement of learning outcomes.

Figure 5 shows a flowchart of the main concepts used to carry out a complete functional project of a piezoresistive pressure sensor such as the one described in this work.
In the PBL process, it is important to make it clear that not all the tools necessary to carry out the engineering project will always be available. Each project has its particularities, and it is often necessary to specifically manufacture a tool to speed up the manufacturing process and ensure repeatability of measurements.

Figure 6 shows a tool that was used to perform a stepped drilling in three parts, the first being the identification of the cutting edge to keep the hole centered where the thread will be made to fix the sensor device. The second has a cutting
edge for perfect seating and sealing of the O-ring and the third for seating the external connection.

Figure 6: Development of tools necessary to manufacture the sensor device.

The interaction and exchange of knowledge between the most experienced professionals (teachers) and new talents (future engineers) positively affect companies and new work relationships and, consequently, economic performance and innovations attributed to trends in the engineering sector or Industry 4.0.

From the point of view of engineering courses, it seems to be a very big challenge to incorporate "new concepts" into the traditional method of teaching and learning.

4 CONCLUSIONS

Individual learning processes are complex and have been studied for a long time to promote quality teaching. The new information that the student receives is related to a relevant aspect in the cognitive structure. The cognitive structure can be influenced by presenting concepts in an explanatory way and using appropriate methods to organize the content and execute the desired project. Therefore, the way the student organizes the content received strongly influences learning. In this work, an encapsulation project for pressure sensors was proposed using multidisciplinary areas of knowledge as a motivating activity.
for students on a mechanical engineering course. The results obtained were conceptual aspects about the main properties of the polymeric materials used, tools for developing prototypes in the laboratory and computer simulation using CAD software.

This work also shows product development concepts and requires great involvement and relationship between the student and the educator during the engineering project execution process.

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