WIP - Applying Project-Based Learning to Awaken New Talents: Experience with a Prototype Essential Oil Extractor

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***Abstract* — This work in progress (WIP) is about the application of project-based learning (PBL) methodology with a group of students from an electromechanics course (high school level) offered in Presidente Figueiredo (Amazonas, Brazil). This WIP aims to relate the concepts of mechanical engineering and chemistry in developing a prototype for extracting vegetable oils from the organic waste of a local food production chain. The theory used was based on Bender's definitions, which anchor the interdisciplinary nature of engineering with the basic sciences to produce a prototype in line with the Sustainable Development Goals (SDGs). During ongoing research, a prototype essential oil extractor was developed via the hydrodistillation technique, prioritizing easily obtainable materials with a simplified construction process. Students conducted research and technical visits to learn about the traditional method of obtaining oils. It was possible to design a prototype distiller on the basis of engineering knowledge in the student's curriculum, especially in materials science and engineering, using the material selection process and organic machine elements. The prototype used easily accessible materials such as PVC pipes, a pressure cooker, pressure hoses, and copper pipes. The first extraction indicated how promising the prototype was, showing a yield of 0.16%, compared with the 1% predicted in the literature. New tests to identify points for improving the prototype are needed. In the self-evaluations, the students highlighted their contribution to the written project, compliance with the timetable, and the connection between the project and their knowledge of electromechanics. They reported being pleased to learn in practice what they had seen in theory, highlighting the link to natural products. In the perception of the researchers, the students showed commitment to the planned activities, excellent initiative-taking collaborative work, and learning autonomy. In this way, the partial results are promising, indicating successful possibilities for innovative transdisciplinary engineering teaching with applications in the actual context of the students, consolidating future talent for engineering careers.**

Keywords— Project-based learning, Career paths, Prototyping

I. Introduction

Researchers, teachers, and managers are discussing alternatives to make teaching more effective. This discussion becomes even more critical when it is limited to secondary school students. As it is a period of discovery and choice, this educational phase can be an essential time for students to access knowledge, innovations, research, and differentiated activities to encourage them to pursue specific careers, such as engineering. PBL is an alternative that contributes to effective learning, where students develop autonomy and centrality.

How students' autonomy can be developed based on others' experiences has been discussed. In secondary school, when PBL is applied correctly, students tend to have the following benefits compared with students receiving traditional teaching: tremendous enthusiasm, excellent content knowledge, extraordinary critical thinking skills, argumentation, scientific-technological knowledge, counterargumentation, and creative and deeper understanding [1].

Various theorists have disseminated this teaching methodology. This WIP uses the perspective of William N. Bender [2], who defines it as an exciting and innovative teaching format in which students select tasks and are motivated by problems in the world around them so that authentic and realistic projects can be created based on motivating questions and tasks that will bring a high level of involvement with the content that is intended to be learned at the end of the project.

The various applications of this methodology lead to different results and objectives. Some studies [3] suggest that projects using PBL can promote interdisciplinarity, in which subjects applied by traditional teaching in isolation can be taught together through projects designed for this purpose.

Considering this context, this WIP uses quasi experimental research [4] to apply the PBL methodology to a group of high school students in the city of Presidente Figueiredo, in the interior of Amazonas, Brazil, intending to relate mechanical engineering concepts to chemistry to promote interdisciplinarity and develop future talent for science and engineering careers in an authentic context: the need to reduce solid organic waste from the food production chain.

II. Theoretical Framework

A. Project-based learning (PBL)

According to the definitions of [2], to be effective, the PBL approach should include several essential elements:

1) Anchor: Project context, background. It can be a paper, a video, a political proposal, or another, as long as it sensitizes the students to the topic to be discussed;

2) Driving question: The basis for starting the project, which provides the general task or goal to be stated for the PBL project, should be something motivating that the students consider potentially significant;

3) Brainstorming: A process in which students survey what they will have to research to answer the driving question, formulating tasks and ideas for accomplishing them;

4) Artifact: Products that are conceived from carrying out the tasks;

5) Authentic performance: This means that learning should be the result of real-world scenarios;

6) Students' voice and choice: This refers to the students' power to decide on project choices.

These concepts, accompanied by the teacher, guarantee the effectiveness of the project as a PBL practice. In addition, according to [2], prior planning by the teacher is necessary, especially concerning the time taken to carry out the activities, the preparation of the anchor and driving questions, and the time taken to monitor the activities, for example, during regular class time or the counter shift.

Another essential concept is the assessment of learning in PBL. As a methodology that differs from traditional educational paradigms, PBL tends to be more reflective and emphasizes deeper understanding, with various alternatives that can be chosen by the teacher, such as self-reflection, rubric assessment, portfolio assessment, authentic assessment, peer assessment, and teacher assessment.

A final determining aspect of PBL used in this research is the publicity of the projects at fairs, schools, and scientific events, among others, as [2] states that students tend to value their work when there is the prospect of presenting it to other people in the community.

B. Target learning content

In this WIP, the subjects are students in their second year of regular secondary school, integrated with professional electromechanics education. The curriculum component of this research is called the Integrating Project. This component aims to integrate knowledge from ordinary high school disciplines with technical education, thus promoting interdisciplinarity between mechanical and electrical engineering knowledge and concepts from chemistry, physics, mathematics, and IT. Considering this context, the proposal was to relate machine elements and materials science as mechanical concepts applied to chemistry themes to be chosen by the students. It considered the studies they carried out in the subjects in progress, prioritizing interdisciplinarity through sustainability.

As a way of situating the proposed technical knowledge with the regular teaching topics chosen by the students, it is possible to highlight the following:

1) Selection of materials for mechanical projects: Mechanical construction materials are potentially linked to producing and manipulating materials for a given purpose. The most critical solid materials for engineering are metals, ceramics, and polymeric materials. Each group has a specific application: metallic materials have greater strength and elasticity and are widely used in structures; ceramic materials are a combination of metallic and nonmetallic materials and have low thermal and electrical conductivity but are more fragile, such as bricks, glass, and abrasives; and polymeric materials have low thermal and electrical conductivity and low mechanical strength, such as rubber and plastics [5].

2) Organic machine elements: As fundamental parts of mechanical designs, these elements can be divided into fastening (bolts, nuts, washers, keys, etc.), support (bearings, etc.), transmission (shafts, gears, etc.), elastic (springs) and sealing elements (gaskets, rings). These materials must be sized and chosen on the basis of the proposed application [6];

3) Hydrodistillation: A process in which water is used as a solvent to extract volatile substances. The raw plant material is immersed in water, and as it vaporizes with increasing temperature, the essential oils (EOs) are released. The steam is condensed, resulting in water and oil, which must be separated via decantation techniques or separators. The resulting EO has a high aroma concentrating compounds [8];

4) Sustainable Development Goals: These are global actions by the United Nations (UN) to address poverty, protect the environment and climate, and allow people to enjoy peace and prosperity. This WIP contributes to SGD #4 - Quality Education, #11 - Sustainable Cities and Communities, #12 - Sustainable Production and Consumption, and #17 - Partnerships. [9].

III. Methods

For methodological purposes, quasi experimental research was used. This method has no random or control group distribution of subjects for treatment. Thus, the conditions for comparing the application of the study are made within the subjects, considering the learning they had before the application.

The research subjects are students aged between 15 and 17 who study at Presidente Figueiredo, Amazonas, in a technical course in electromechanics integrated with high school. These students took part in a class with approximately thirty students. In each group of 2 or 3 students, a PBL project was applied, varying the knowledge of the common core integrated into the technical core. This WIP focuses on a group researching the interdisciplinary nature of mechanics and chemistry.

During the planning phase, the table I built with the sentences and phases of the PBL unit facilitated monitoring the work and made the elements more accessible.

At the beginning of the work, the teacher determined the anchor by defining the National Science and Technology Week (SNCT) 2023 theme. SNCT is a national event involving most institutions that hold events with a common theme, such as exhibitions, short courses, workshops, etc. This year's theme was "Basic Sciences for Sustainable Development." The choice of a scientific event as an anchor was due to the characteristic cited by [2] that students can give more value to their project when there is the possibility of presenting it to the community. On the basis of this anchor, other project elements were determined and are described in Table 1.

TABLE I. TABLE WITH PHASES OF THE PBL

PBL Element	*Application in the Project*
Anchor	SNCT theme: "Basic sciences for sustainable development" with presentation of videos about the event.
Driving question	How do we combine mechanical and chemical concepts to build a prototype related to the SNCT theme?"
Tasks	1. Learn about the conventional hydro distillation process. 2. Conduct research into replacing the traditional process with a low-cost prototype. 3. Design the construction of a prototype, selecting materials and machine elements. 4. Build the prototype. 5. Extract oils using the prototype. 6. Perform statistical and chemical analysis of the samples.
Planned artifacts	1. Report on a technical visit to a company with a conventional extraction process. 2. Review literature on prototype essential oil extractors. 3. Project diagram in drawing form. 4. Prototype built. 5. Analysis reports.
Learning Assessment	Reflective self-assessment guided by the teacher

The first task was a technical visit to the Brazilian Agricultural Research Corporation (Embrapa) Amazônia Occidental based in Manaus.

With respect to the planned artifacts 4 and 5 of prototype design and construction, the students used knowledge from theoretical references such as [5] and [6] to select the most suitable materials and parts for the application. The construction itself took place in the institution's mechanics laboratory. Task 5, the extraction of essential oils, occurred in the school's chemistry laboratory.

Given the school's limitations, the last analysis selected as the task to produce the analysis report artifact took slightly longer than expected. Another campus of the same institution was chosen for the study. Given the time allocated for this activity, the results are still preliminary.

It is believed that the elements chosen make up a good possibility for applying PBL, according to [2], and the work results can be seen from the artifacts built and the student's self-assessment. The evaluation of artifacts combines rubric evaluation [7] and assessment by external teachers. The self-assessment used ten questions, five open and five closed, which encouraged reflection on the organization of the work, research conducted, collaborative work, specific topics researched, and the experience of presenting to the community. It was applied after the construction of artifact 4.

IV. PRELIMINARY RESULTS

The preliminary results were the artifacts produced in each section, with a brief presentation of the evaluation carried out on each artifact.

A. *Technical visit report*

The technical visit conducted by the students at Embrapa explored laboratory methods of extracting EO, enriching the team's knowledge of the subject with field research. An extensive literature review was then conducted to provide a theoretical basis for the project. A technical visit report was drawn up as an artifact of this task.

The students used Google Scholar and Periódico Capes as databases. The terms "prototype extractor," "essential oil," and "extraction by hydrodistillation" were used as keywords. Many papers were found, but by applying the exclusion criterion of only articles on prototypes, 12 were selected. The papers showed good construction possibilities for building a prototype with better results and other material alternatives.

From the report, in a rubric assessment, the teacher noted that the students understood all the stages of oil extraction by hydrodistillation, most of the technical processes, and all the mechanical equipment used.

B. *Mechanical design: layout and materials*

After the technical visit and the research, the students moved on to the design phase with the selection of materials and parts. A summary of the materials selected is shown in Table II.

TABLE II. PROTOTYPING SELECTED MATERIALS

Materials	*Specification*	*Type of Material*	*Quantity*
Heat source	Flame or heater	Metallic	1
Pressure cooker	5 L	Metallic	1
Polyvinyl chloride pipe	Diameter 100 mm	Polymetric	0.5 m
Flexible copper tube	3/8" diameter	Metallic	3 m
Guide connectors	¼" to 3/8"	Metallic	4
Spigots	¼” to ¼”	Metallic	6
Washers	17 mm internal diameter	Metallic	4
Crystal hose	¼" internal diameter	Polymetric	0.5 m
Pressure hose	¼" internal diameter	Polymetric	4 m
Styrofoam box	-	Polymetric	1
Water pump	1 m of water lift or higher	Metallic/ Polymetric	1
Silicone	For elevated temperatures. Up to 300°C	Ceramic	1

Because of the rubric assessment, it was clear that the students chose the materials correctly, with the expected knowledge of material selection. Most of the materials used in structural design are metallic and are used mainly in direct contact with steam and EO. Polymetric materials were also used for connecting elements and fluid conduction. Fewer ceramic materials were used to ensure sealing. The scheme designed by the team is shown in Figure I.

C. *Prototype built*

A view of the improved prototype assembled in the laboratory is shown in Fig. II.

The learning assessment of this construction also used a rubric assessment, which revealed that the students did not have complete knowledge of the assembly tools and that the materials chosen, however, were adequate. The demonstrations given by the teacher overcame the difficulty they had with some tools.

FIGURE I. SCHEMATIC DRAWING OF THE PROTOTYPE

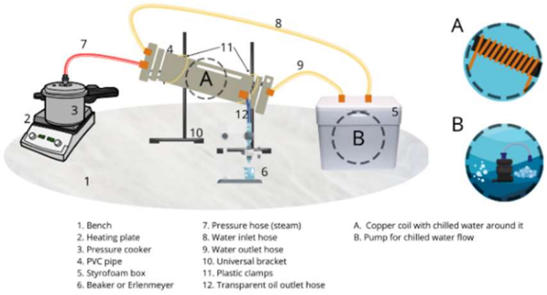

FIGURE II. IMAGES OF THE BUILT PROTOTYPE

D. Extracted oils (EOs): initial analyses

After the extraction prototype was mounted, a test series was conducted to observe the effectiveness of the extractor (Table III).

TABLE III. PRELIMINARY ANALYSIS OF EXTRACTED OILS (EOs)

Vegetable raw material	*Quantity of material*	*Extraction time*	*Result*
Cymbopogon citratus (Holy grass) cut	100 g	5 h	Hydrolate and oil bubbles
Cymbopogon citratus (Holy grass) crushed	100 g	3 h	0.855% yield of essential oil
Syzygium aromaticum (Clove) whole	100 g	4 h	Hydrolate only
Plectranthus barbatus (garden boldus) crushed	200 g	3 h	0.04% yield of essential oil

Some extractions produced only hydrolate, and the students noticed procedural problems such as a lack of grinding and difficulty in temperature control. By checking these problems, they could adjust and correct the parameters. For the chemical analyses, the students compared extractions from the prototype with the traditional method (Clevenger's system) using the same plant material, *Plectranthus barbatus* leaves. In terms of yield, the results are in line with the literature [8].

Initial gas chromatography–mass spectrometry (GC–MS) analysis revealed the common compounds caryophyllene and caryophyllene oxide (both sesquiterpenes). The results of GC–MS for the EO obtained with the prototype also identified components common to other plants, such as citronellol and eugenol. This result was interpreted as cross-contamination inside the prototype, which required a cleaning protocol between extractions.

The learning evaluation for this stage consisted of a rubric assessment of the analysis reports handed in by the students, which showed that the students understood the details of the hydrodistillation process from the practical tests, that they knew how to carry out initial analyses and that for more complex analyses, they would need a professional in the field.

E. Other learning assessments

In addition, two other evaluations were carried out: evaluation of the final artifact by teachers external to the project and self-evaluation.

The three external teachers considered the relationships between the project and the course, creativity, clarity, quality of the items presented, and technological innovation. The students received full marks for all the items.

In [2], the self-assessment provided vital clues about the students' learning from this work. For them, it is possible to state that sufficient research was done on the project's themes (70%), that the project was presented in the most appropriate way (100%), and that knowledge studied in a theoretical way was applied, such as "mechanical fasteners," refrigeration systems, chemistry, biology and that, in their view, subjects from different disciplines had to be studied together. One aspect that marked the students' reflections was the possibility of presenting at science fairs and that they wanted to do this on several occasions, including in future careers in science and engineering. The overall rating for the team members for the project is 80 on a scale of 0 -100.

V. CLOSING DISCUSSION

The development of this ongoing work has produced much learning and team engagement. Applying PBL techniques in a real classroom context has resulted in fascinating artifacts, highlighting that a well-constructed project with this methodology, considering all its concepts, can be particularly good for engineering teaching.

This finding shows that teachers position PBL as an alternative for planning innovative activities to promote interdisciplinarity and the discovery of new talent in engineering and science. Many teachers want to relate specific knowledge to general knowledge, and the practice presented here is an exciting alternative.

Notably, the favorable external evaluations and the student reflection process indicate that students, at the heart of the learning process, position themselves and recognize points of researched content, highlight collaboration among themselves, and are concerned about scientific dissemination to the community in general.

Therefore, this WIP has met its objectives and, considering the still preliminary results, will produce other knowledge that will contribute to the research and academic literature in engineering education.

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