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ARTICLE

CONSTRUCTION OF A DIDACTIC WIND TUNNEL AS A PEDAGOGICAL APPLICATION IN TECHNICAL EDUCATION

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ABSTRACT: A didactic wind tunnel was designed and built as a pedagogical proposal aimed at teachers and students of a technical course in mechatronics integrated into the high school at the Federal Institute of São Paulo. The proposal aimed to analyze the learning results from the implementation of the project added to an experimental test; as well as to investigate the integration of contents and the interdisciplinarity in this didactic practice, and also present the technical-mathematical analysis involved in the construction of the equipment and the experimental test. The simultaneous and integrated approach between analysis of pedagogical practice and technical-mathematical investigation constitutes a differential of this research. Positive points arising from the pedagogical practice were evidenced and may support future didactic interactions in the development of projects with experimental testing. Besides proving existing theories about air dynamics, the proposal sought to bring students closer to the universe of applied science through a dialogic and encouraging teacher mediation, as well as providing a holistic view between theory and practice set in high school integrated with professional and technological training.

Keywords: school project, pedagogical practice, interdisciplinarity.

CONSTRUÇÃO DE UM TÚNEL DE VENTO DIDÁTICO COMO APLICAÇÃO PEDAGÓGICA NO ENSINO TÉCNICO[1]

RESUMO: Um túnel de vento didático foi projetado e construído como proposta pedagógica voltada a docentes e discentes de um curso técnico em mecatrônica integrado ao ensino médio do Instituto Federal de São Paulo. A proposta teve como objetivo analisar os resultados na aprendizagem a partir da execução do projeto agregado a um ensaio experimental, assim como averiguar a integração de conteúdos e a interdisciplinaridade nessa prática didática além de apresentar a análise técnico-matemática envolvida na construção do equipamento e no ensaio experimental. A abordagem simultânea e integrada entre análise da prática pedagógica e investigação técnico-matemática constitui-se em um diferencial desta pesquisa.

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Pontos positivos advindos da prática pedagógica foram evidenciados e podem subsidiar interações didáticas futuras no desenvolvimento de projetos com ensaio experimental. Além da comprovação de teorias existentes sobre dinâmica do ar, a proposta buscou aproximar os discentes ao universo da ciência aplicada por meio de uma mediação docente dialógica e incitante, assim como fornecer uma visão holística entre teoria e prática ambientadas no ensino médio integrado à formação profissional e tecnológica.

Palavras-chave: projeto escolar, prática pedagógica, interdisciplinaridade.

CONSTRUCCIÓN DE UN TÚNEL DE VIENTO DIDÁCTICO COMO APLICACIÓN PEDAGÓGICA EN LA EDUCACIÓN TÉCNICA

RESUMEN: Se diseñó y construyó un túnel de viento didáctico como propuesta pedagógica dirigida a profesores y alumnos de un curso técnico en mecatrónica integrado en la escuela de enseñanza secundaria Instituto Federal de São Paulo. La propuesta tuvo como objetivo analizar los resultados de aprendizaje de la ejecución del proyecto sumado a una prueba experimental, así como verificar la integración de contenidos y la interdisciplinariedad en esta práctica didáctica y también presentar el análisis técnico-matemático involucrado en la construcción del equipo y en el ensayo experimental. El abordaje simultáneo e integrado entre el análisis de la práctica pedagógica y la investigación técnico-matemática constituye un diferencial de la investigación. Se evidenciaron puntos positivos derivados de la práctica pedagógica y que pueden apoyar futuras interacciones didácticas en el desarrollo de proyectos con pruebas experimentales. Además de probar las teorías existentes sobre la dinámica del aire, la propuesta buscó acercar a los estudiantes al universo de las ciencias aplicadas a través de una mediación didáctica dialógica e incitadora, así como brindar una mirada holística entre la teoría y la práctica ambientada en la escuela secundaria integrada con la formación profesional y tecnológica.

Palabras clave: proyecto de escuela, práctica pedagógica, interdisciplinariedad.

INTRODUCTION

Professionalizing technical education has the formative ideal to promote the integral development of the student for performance in the job market, promoting social, scientific, and economic progress. To achieve this goal, teachers have opted for different teaching approaches, not based on methodologies that imply autonomy and freedom for taking actions in the profile of the professional future. In this sense, the pedagogical practice has been enhanced and energized to supplant the traditionalism that permeates the teaching-learning process.

Not technically, scientific knowledge can acquire meaning within a broad, well-structured context. Robilotta (1985) explains that there are only cases in which the didactic system fails to fully account for its complexity because it is fragmented into successive educational activities, such as chapters or books, which end up being perceived by some as a series of disconnected information. On the same reasoning, both theory and practice do not teach, but they do not need to be dichotomous, they can also appear in the understanding of certain technical knowledge, depending on the pedagogical approach.

Technical courses aimed at the industrial sector present in their right the association between theoretical and practical classrooms, a characteristic considered essential to enter and act with performance in the professional environment. This pure combination, as consecrated in its conception, is mistaken from time to time in terms of its objective, depending on the teaching strategy used in the articulation of these teaching elements. Along these lines, the development of projects and experimental activities are methodological alternatives that tend to facilitate the connection between theory and practice. However, despite the prevailing discourse in favor of the use of these methodologies, given by a large part of the teachers in the technical area, substantial achievements of this group have not yet been observed to attach them to their didactic practices in an incisive and fully successful manner.

In the development of projects and experimental practices, there is no consensus or systematization in conducting the activity, which explains the different results (positive or negative) arising from these teaching-learning processes. When the methodology does not fulfill its function and exempts the student from integral learning, it is necessary to rethink it or, at least, find arguments that justify its use, eradicating the idea of using it simply because of tradition or dogmatism. In this perspective, the proposal of this research comes to the fore, seeking to rethink and problematize the development of a project (technical-didactic-experimental equipment) aimed at full learning, which encompasses intellectual aspects and mathematization capacity and technical-procedural execution.

The literature reveals recent works whose objective is the construction of various technical-didactic equipment for school applications with students from the technical area (BEZERRA, 2018; NAKASONE, 2018; ARAÚJO et al., 2020; MESQUITA et al., 2020; OLIVEIRA et al., 2020), more than they do not represent mathematics and experimentation, they do not show a methodological procedure and do a superficial analysis of pedagogical practice. Investigative incompleteness, vague conduction process, and gaps of technical-mathematical information are elements that hinder a faithful reproduction of projects like these in search of comparative learning results since they do not offer a structure of collected data capable of reflecting the formative integrality of students. There seems to be a common sense of the modus operandi for the development of projects in the technical area (electro-mechanics) of professional education, focusing on qualitative aspects (understanding of physical phenomena) to the detriment of the quantitative ones (technical-mathematical-experimental procedure necessary for the market of work). It is proposed here to break this single way of doing things through the development of a project for studies on air dynamics, aimed at a technical level course integrated into the secondary school, without understanding that both aspects, qualitative and quantitative, are relevant in the student's formative process.

One of the ways to study air dynamics is through the use of a wind tunnel, a mechanical device that allows the visualization of aerodynamic phenomena on surfaces and bodies. In this work, a didactic wind tunnel is designed and built to perform aerodynamic tests. The proposal is to carry out this activity to improve the teaching-learning process, whose aim at analyzing the results in learning from the development of this project composed of an experimental test; verifying the integration of contents and interdisciplinarity in this didactic practice and; presenting the technical-mathematical analysis involved in the construction of the equipment and the experimental test. The simultaneous and integrated approach between analysis of pedagogical practice and technical-mathematical investigation constitutes a differential of this research when compared with similar works found in the literature. The activity was carried out by teachers and students of the Technical Course in Mechatronics Integrated to High School of the Federal Institute of São Paulo, IFSP campus Catanduva. With the research agenda delimited, we sought to highlight positive points arising from the pedagogical practice that can subsidize future didactic interactions in the development of projects with experimental essays. Furthermore, the proposal sought to provide a holistic view between theory and practice, aiming to contribute to the construction of knowledge through the search for a critical and liberating educational activity.

THEORETICAL REFERENCE

Project with an experimental essay as a better educational process

Activities with projects can be applied in all areas of knowledge and teaching levels because it is characteristic of the human being to develop projects and seek solutions, a fact that favors the production of knowledge (FAGUNDES, 1999). Learning through projects constitutes an active training strategy, in which a practical activity is included as a teaching mechanism. This methodology is based on hybrid teaching characterized by the interaction between different disciplines with the use of different resources. The exploration of a context, the development of ideas, and the communication between those involved in the project are the important aspects of the teaching practice that seeks to improve the training of students.

The experience of teachers in the development of school projects with their students has shown that this educational practice contributed to the qualification of individuals, both teachers, and students, as well as the development of critical and creative awareness. As stated by Prado (2003), a project coordinated by teachers strengthens emancipatory competencies and is associated with new experiences that imprint a reflective and investigative posture on the teacher, or that corroborates with the vision of education of Delors et al. (1996), which education must be concerned with the constant updating of knowledge and the awakening of skills to adapt to and the circumstances of life in society, restructuring the teaching position. Concerning students, Matos (2011) states that the student who participates in a school project assumes a protagonist role in the learning process, not being limited to simply being a receiver of information. The development and execution of a project by the student create an opportunity for different learning and skills to be developed to respond to different social and professional demands (MAINGAIN; DUFOUR, 2008). In this sense, Pacheco (2011) links cognition to competence in the development of projects by students, referring to the capacity that reveals the mastery of a set of knowledge that can become visible in a given context of action.

The pedagogical proposal of teaching based on projects is well contextualized by Hernandez (1998) and Martins (2001), who claim that this methodology creates more dynamic and effective learning situations. Hernandez (1998) considers that this pedagogical modality can qualify individuals for the needs of the world of work and life in modern societies. He also adds that the projects contribute to the construction of subjectivity, bring the contents closer to practical experience and enhance the understanding of the various factors of a phenomenon. For Martins (2001) a project as a pedagogical proposal establishes a balance between scientific thinking and human development, as it is based on a methodology that has as its tripod: curiosity, investigation, and discovery. According to the author, this methodology leads the active subjects of the project to the mastery of renewing didactic skills, going through the discussion until the confirmation of conjectures about the facts, including creative analysis of deductions and conclusions.

When the project involves experimental activity, greater challenges can arise when compared with the execution of purely theoretical projects. In the view of Silva (2017), among the main difficulties and barriers to be overcome in the elaboration of an experimental project are the motivation, the time for preparation and development of the project, and the availability of materials, equipment, and space. Maldaner (2013) also warns of the difficulties in demystifying the common sense of students who idealize some experimental activities as spectacular and inexplicable phenomena, commonly reinforced by fiction in the media through alchemical practices, which are launched in the imagination of students outside their reality context.

Even though these obstacles exist, projects with experimental trials fear the differential of enabling the student or scope of significant learning from the establishment of a solid relationship between theory and practice. Borges (2002) infers that the involvement of the student in experimental activities provides the debate of interpretations and ideas about observations and phenomena to produce knowledge. Oliveira (2003) highlights the relevance of theory and practice as fundamental complements to the enrichment of learning, assuming that the development of projects makes it possible to perceive the concept of theory-practice in a relationship of distinction and dependency. In the same direction, Moura and Silva (2014) argue that experimentation and theory are interdependent and Silva et al. (2019) defend that experimental practice always articulates the phenomenon and the theory, correlating either doing or thinking.

In the context of the exact sciences, the development of projects with experimentation based on questioning is extremely necessary since expository classes in this area tend to be less attractive because they are based on theoretical data, laws, equations, and calculations. Marcondes and Peixoto (2007) indicate the importance of experimental projects in the area of exact sciences when they state that, without this practice, the teaching process is restricted to low cognitive levels, centered on the teacher with essentially expository classes and with no relationship between content and every day. In the same way, Pontone Junior (1998) points out that experimental practice in exact sciences helps to minimize teaching based only on the transmission of concepts, which gives students an aversion to the subjects addressed in the face of this way of teaching being limited to decorated contents.

The current literature reveals a variety of works with experimentation in the area of exact sciences linked mainly to teaching Physics (BARBOSA et al., 1999; SENRA; BRAGA, 2014; ROSA; ALVES FILHO, 2014) and Chemistry (MORAES et al., 2007; MACHADO; MÓL, 2008; GUIMARÃES, 2009) aimed at high school. Many of these studies tend to focus their analyzes on pedagogical practice, listing the difficulties of students and teachers in developing the activity, as well as identifying the positive points and content assimilated in this educational context. Others focus on technical-mathematical analysis and procedures for carrying out the experimental test. The absence of a simultaneous and integrated approach to the items "pedagogical practice" and "technical-mathematical analysis" or the superficial treatment of one of these items makes it unfeasible for other researchers to faithfully reproduce the experimentation with other students in search of comparative learning results. From this perspective, Araújo and Abib (2003) analyze studies available in the literature that address experimental activities in Physics in high school, dividing the works found into two groups, qualitative and quantitative. Those with a qualitative approach were based on methodological aspects, while those with a quantitative character were linked to more expressive levels of the mathematization of the problem. However, there were no works concomitantly framed in the two investigated groups. Studies involving the construction of a didactic wind tunnel are found with a quantitative focus in the literature and aimed at higher education (SOETHE et al., 2011; LUAN; NOGUEIRA, 2017; SOUZA; OLIVEIRA, 2018; QUEIROGA; VIANA, 2021).

In addition to the analysis of pedagogical practice, in a technical course integrated into high school, the systematic conduction and execution of the experimental activity of a project in the area of exact sciences, ruled by complete technical-mathematical analysis, is essential for students to be able to incorporate learning in a concatenated way. In the case of the Technical Course in Mechatronics Integrated to High School at the Federal Institute of São Paulo, Catanduva campus, one of the prerogatives of the egress is to work in the industrial sector in mechanical and electro-electronic processes, to design, install and operate equipment, with these actions in total consonance with the development of a project with an experimental test whose system for experimenting is well defined.

There are no projects in the literature with experimental tests, in the field of mechanics, that are focused on the analysis of the pedagogical process simultaneously and integrated with the technical procedure for obtaining results. The construction of a wind tunnel as a pedagogical proposal is in line with what Brasil (2006) prescribes, that practice and experimentation must not be forgotten in pedagogical action and must be confronted with historically instituted concepts and theories, constituting in dynamics with antecedents, implications, and limitations. However, if the technical-mathematical procedure is treated perfunctorily, it is not possible to clearly know how the concepts and theories were opposed to the experimental practice within the pedagogical proposal. To associate the dyad pedagogical practice and technical-experimental procedure in a school project, the construction and experimental test of a wind tunnel translates into a proposal that allows the investigation of both aspects.

Furthermore, as pointed out by Auler and Delizoicov (2001) and Praia et al. (2007), a minimal understanding of issues related to technology and science is essential for building citizenship, issues that are of fundamental importance for students of integrated technical education at the secondary level. Thus, the development of the project as a teaching strategy also seeks to contribute to the formation of subjects able to exercise citizenship, with better conditions to exercise the capacity for dialogue, argumentation, deduction, and intervention in various problems of the social sphere.

Integration of different content and interdisciplinarity in the development of projects

The development of projects as a pedagogical practice allows the simultaneous application and integration of different contents addressed in different disciplines. As Ausubel (2003) infers, students' prior knowledge is an essential variable for meaningful learning. For the author, new knowledge acquires meaning when it finds interactive anchorage with some particularly relevant prior knowledge. According to Battistel et al. (2007), using students' prior knowledge, such as that acquired in course disciplines, enables the perception between the inconsistency of their knowledge and the observed reality, which implies conceptual change. In this direction, Souza et al. (2013) argue that it is possible to develop scientific knowledge combined with previous knowledge. Pozo and Crespo (2009) also add that scientific and everyday knowledge is compatible and for this reason, are related to each other.

The integration and simultaneity of different contents in the development of projects meet the conception of professors in the technical area about interdisciplinarity that, according to Dal Molin et al. (2016), consists of the relationship between the disciplines and the integration of their themes. From this perspective, Rehem (2016) addressed interdisciplinarity in the construction and planning of didactic devices, relating them to productive processes and the labor market, which required a practice based on theory. Ysa (2018) related pedagogy and exact sciences, integrating the various disciplines in a specific project to measure pressure in a Venturi tube, constituting a value judgment for the construction and appropriation of knowledge.

According to Japiassu (1976) and Demo (1997), there are different approaches to interdisciplinarity. However, Japiassu (1976) asserts that interdisciplinarity aims to combat three points linked to the learning process: the fragmentation of knowledge, the dissolution of the complex, and the overcoming of imposed models. Among the conceptions of interdisciplinarity, the one from Fazenda (2011) stands out, which assumes that there must be a dynamic interaction between disciplines through a mutual process of knowledge, aiming to intertwine the senses for the promotion of knowledge from the communication between individuals based on reciprocity.

Cascino (2004) warns against reductionist pedagogical practices to the simple crossing of disciplines or parts of the disciplinary contents, which may not be effective in the learning process since there is no interdisciplinarity. According to the author, as well as to Fazenda (2002, 2011, 2012, 2014), interdisciplinarity requires a look beyond the relationships between disciplines, and there must be dialogue and appreciation in the relationships produced between teachers and students in the teaching-learning process. Hartmann and Zimmermann (2007) also argue that there should be an integrated work between teacher and student, as well as Augusto and Caldeira (2007) state that there is a need for collective discussion, under teacher mediation, for the development of more effective teaching. Pedagogical practices that can be confused with interdisciplinarity are multidisciplinarity and pluridisciplinarity. Japiassu (1976) and Trindade (2004) explain that multidisciplinarity is characterized by the simultaneous application of a single theme by several disciplines, without, however, integration and real cooperation between them. For the authors, in pluridisciplinarity there is an interaction between the subjects of the disciplines, with a view of the object of study from different angles and without dialogue between the parties involved. Ferrari (2007) points out that these two terms need to be transposed because they do not cooperate to overcome the fragmentation of knowledge, such as interdisciplinarity. It can then be seen that, for each format of didactic interaction, the relationship between disciplines and contents is orchestrated differently, with interdisciplinarity being the form most defended by researchers.

Regarding the integration of contents and interdisciplinarity inserted in the development of projects, positive notes of this pedagogical practice can be observed. For Martins (2001), when the project methodology is interdisciplinary and the scope of the knowledge area is greater, the different disciplines are related to deepen knowledge, make studies more dynamic and interesting, in a way that a discipline helps the other, favoring investigation, the construction of new concepts and the taking of attitudes in the face of real facts. Almeida (2002) adds that disciplinary boundaries are broken by the integration of contents in the development of projects. The breaking of these boundaries allows the integrating of the disciplines in the course of investigations, deepening them vertically in their reality concomitantly with the establishment of horizontal articulations in a relationship of reciprocity between them, having as a backdrop the uniqueness of knowledge under construction. Morin (2015) is even more adamant when he states that the integration of content fostered by the development of projects seeks to solve global and complex aspects of learning, in which students are unable to articulate the contents and knowledge acquired in isolation.

In this way, the integration of contents and interdisciplinarity in projects constitutes an effective practice in search of the improvement of the teaching-learning process. Working on these aspects becomes necessary and at the same time a challenge. The literature presents several discussions about interdisciplinarity and content integration, but it does not focus or exemplify practical applications of these concepts in activities with projects, even aimed at technical education in the area of mechanics and air dynamics.

The wind tunnel is a device widely used in aerospace and automotive construction. Therefore, it has a practical application for jobs that may be developed by future professionals. Such work has interdisciplinary characteristics and generally requires a joint effort by the individuals involved, based on highly critical dialogue and discussion. Solid specific technological training is the foundation for dealing with real situations, in which daily knowledge and thinking are essential for the job market. Thus, the construction of a didactic wind tunnel as a pedagogical practice, seeking to integrate different contents with interdisciplinarity in the project, becomes of high collaborative value in building qualified professionals for the labors and requirements of the mechanical industrial sector, and in addition, this activity represents the deconstruction of traditional educational practices in this area.

METHODOLOGICAL PROCEDURES

Empirical-pedagogical approach

According to Almeida and Szymanski (2010), the design of research procedures and data analysis depends on the methodological process chosen by the researcher. The focus of this work is the construction of a wind tunnel as a pedagogical proposal, which is intended: to analyze the results of learning from the development of this project composed of an experimental test; to verify the integration of contents and interdisciplinarity in this didactic practice and; present the technical-mathematical analysis involved in the construction of the equipment and the experimental test.

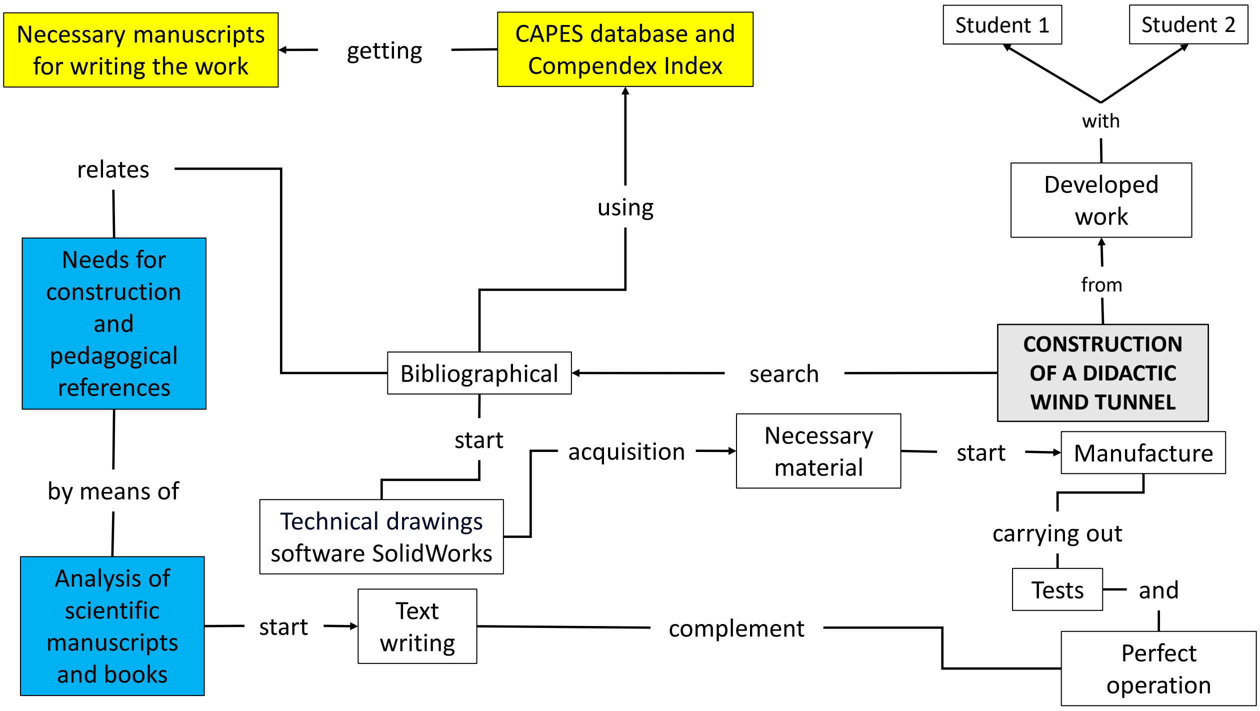
For the analysis of the first two pretensions mentioned above, a qualitative methodology was used. Santos and Greca (2013) argue that qualitative research facilitates the understanding of a given educational situation. The positive aspect of a qualitative approach is obtaining explanations in greater depth about the research object (MILES; HUBERMAN, 1994). Fortin (2009) states that, in qualitative research, the researcher is focused on understanding the phenomenon under study.

To characterize the pedagogical activity, the project was supported by the prescription by Teixeira and Megid Neto (2017) on the research of an interventional nature, which is configured by the articulation between investigation and knowledge production, involving action and interventional processes. Included in this modality, *application research* aims, among its objectives, to evaluate didactic practices and strategies related to the teaching-learning process. In this sense, application research was the category considered for the theoretical-methodological framework of the proposed practice.

The participants in the project were two professors in the field of mechanics and two students, all linked to the Technical Course in Mechatronics Integrated to High School at the Federal Institute of São Paulo, Catanduva campus. The professors, in addition to being participants, acted as mediators of the activity. The number of participating students is linked to the need for teacher monitoring to guarantee the safety of students in handling the equipment and machinery of the mechanical manufacturing laboratory for making the parts of the wind tunnel.

The proposal for conducting the project was organized together with all those involved. A conceptual map was made for the development of the project as a whole, Figure 1, following the plan presented by the MEC ([n.d.]). This map is a tool that assists in the development and sequence for the execution of a project, displaying the steps hierarchically (NOVAK; CAÑAS, 2010) and facilitating the visualization of the result and conclusion of the work. The open-platform CMapTools software, developed by the Institute for Human Machine Cognition at the University of West Florida, was used, which uses a flexible architecture (IHMC, [n.d.]) to make the map.

Figure 1 - Concept map for wind tunnel construction



Source: Our authorship.

Weekly meetings between professors and students were held to guarantee the uninterrupted development of the project as well as the taking of interventional actions to stimulate the students' cognitive abilities. The interventions were based on a dialogic perspective, compelling the students to reflect on the search for solutions regarding the aspects: conceptual and procedural doubts for the experimental test, technical-mathematical mistakes, direction for bibliographical research, and difficulties of other natures such as choice of materials, components, and handling of specific software. The teaching follow-up allowed for gathering information that, added to the technical reports delivered by the students, constituted a list of references to guide the data collection process at the end of the project.

Data collection and the evaluation of the pedagogical practice were performed using the focus group technique (GOMES; BARBOSA, 1999; DIAS, 2000; CRUZ NETO et al., 2002). As stated by Morgan (1997), in the focus group technique, there is data collection through interactions between individuals when discussing a specific topic. Veiga and Gondim (2001) point out that the focus group constitutes a resource to understand the construction process of individual perceptions. The focus group technique follows Thiollent's line of thought (2011) that, when the structure of the research subjects is organized simply and easily to carry out discussions, it is possible to collect and analyze data from the narrative of those involved in the activity. According to Gondim (2003), the use of focus groups is also related to the assumptions of the researcher, who resorts to this technique with a specific vision or purpose. In the case of building the wind tunnel as a pedagogical proposal, the focus group is a way of gathering perceptions to improve the teaching-learning process, in addition to promoting self-reflection in students regarding the interconnection of subject contents with real projects.

Project and construction of the wind tunnel

The wind tunnel developed for educational purposes with a simple construction presents all the basic specifications of test equipment. Besides the wind tunnel, an aerodynamic profile was also built and inserted inside the tunnel for the experimental test. The development of the project was divided into 7 stages, as specified in Chart 1.

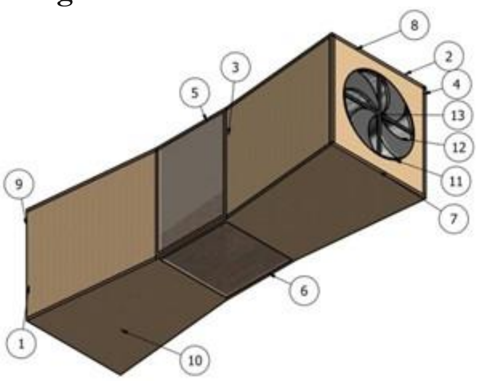
Chart 1 – Stages for wind tunnel development.

STAGE	ACTIVITY
1	Bibliographic research
2	Design and drawing in the *software SolidWorks®*
3	Acquisition of materials and components
4	Making of parts
5	General assembly and operation
6	Construction of the aerodynamic profile
7	Experimental test

Source: Our authorship.

The bibliographic research stage was carried out in search of similar projects and verification of characteristic dimensions for the construction of a small wind tunnel. In the second stage or wind tunnel, its parts and components are designed and developed using SolidWorks® software. Figure 2 shows the general view of the wind tunnel with each of its parts identified. The structure is divided into 13 parts, some of which are made by students on their campus and others purchased on the market.

Figure 2 - Wind tunnel overview.



Source: Our authorship.

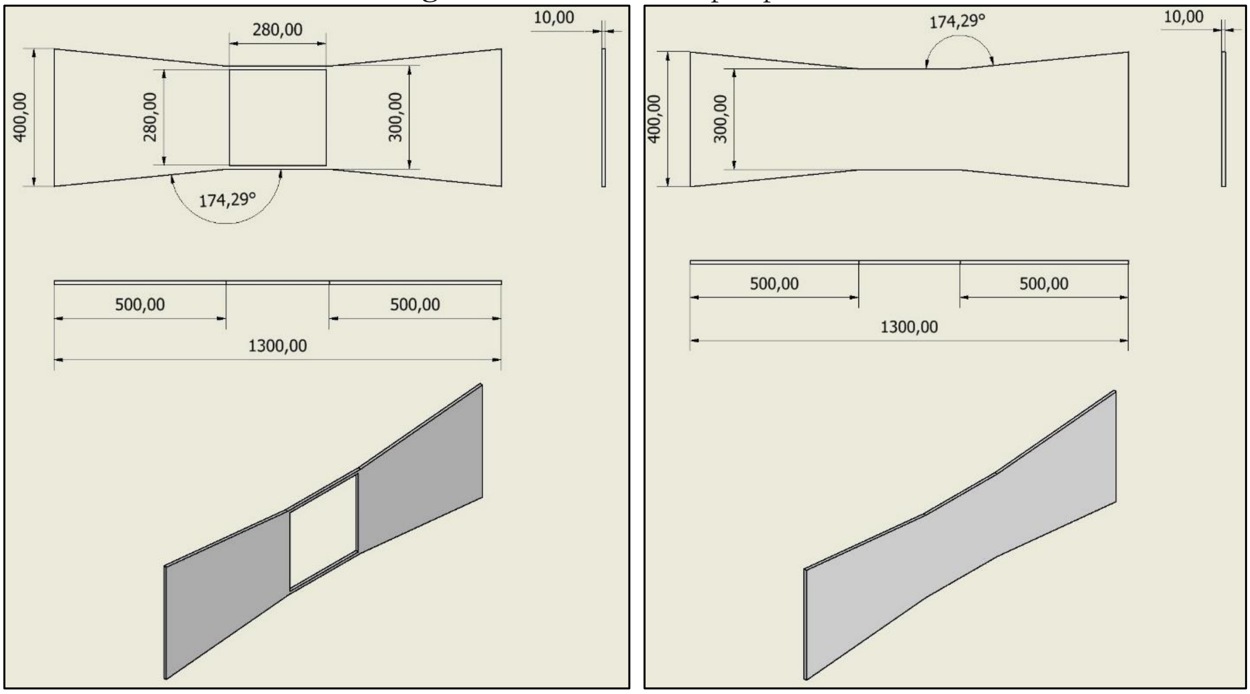
The parts with numbers in Figure 2 are:

- Part 01: Air suction filter, which organizes the airflow, eliminating interference in the test;
- Part 02: Exhaust fan with 300 mm diameter and ¼ HP motor;
- Part 03: Internal zinc plate, also responsible for organizing the airflow and reducing the turbulence generated by the internal walls;
- Part 04: Zinc plate, opposite to “Part 3”, with the same function as the previous one;
- Part 05: Transparent acrylic plate for viewing the rehearsal area;
- Part 06: Transparent acrylic plate for viewing the test area, opposite “Part 05”;

- Part 07: Tunnel side support structure;
- Part 08: Lateral support structure, opposite and symmetrical to “Part 07”;
- Part 09: Tunnel top structure;
- Part 10: Lower structure of the tunnel and symmetrical to “Part 09”;
- Part 11: Exhaust frame and cradle;
- Part 12: Exhaust fan;
- Part 13: Propeller fixing pin on the armature.

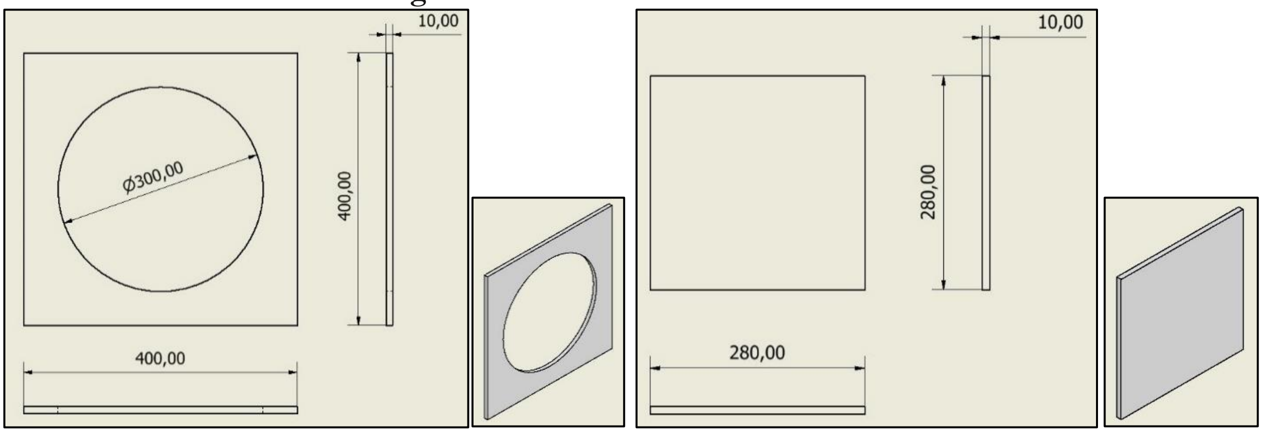
Figures 3 and 4 show plan and perspective views with the dimensions in millimeters of the structural parts of the wind tunnel.

Figure 3 - Side view and perspective.



Source: Our authorship.

Figure 4 – Extractor Hood dimensions.



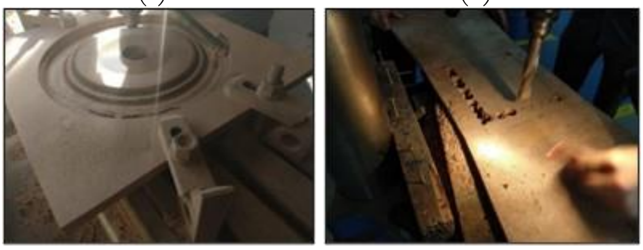
Source: Our authorship.

In the third stage of Chart 1, 10 mm thick MDF (Medium Density Fiberboard) boards were used to assemble the tunnel structure. This material was chosen because it has been an abundant product since the 1980s (ELEOTERIO, 2000) and is also a reforestation wood for short rotation and relatively low cost (DIX; MARUTZKY, 1997). A 300 mm diameter wall exhaust fan with a ¼ HP single-phase electric motor was used to provide airflow in the tunnel. An Arduino® MEGA board (ARDUINO, 2015) was used to control the fan rotation. A 220 Volt LED light bus was installed in a gutter in the upper inner part of the wind tunnel to facilitate the visualization of the airflow over the aerodynamic profile. To obtain the air velocity in the region of the test area, a Pitot tube was used. To organize the airflow, zinc plates were used on two inner walls of the tunnel, and an air suction filter on the opposite side of the exhaust. An acrylic plate was used as a screen for viewing the test area.

The MDF sections were submitted to the machining processes, stage 4, giving rise to the different constituent parts of the wind tunnel, in exact dimensions, according to the previous drawings shown in Figures 3 and 4. In stage 5, the set of MDF pieces used was properly assembled and the other components necessary for the tunnel were installed and their operation tested. Figure 5 shows images of the tunnel parts manufacturing process. Figure 6 shows the assembled structure of the tunnel and details of the installed exhaust.

Figure 5 - Tunnel parts manufacturing process: (a) exhaust pipe, (b) test area display screen.

(a) (b)



Source: Our authorship.

Figure 6 - Mounted structure of the tunnel and details of the installed exhaust.

Source: Our authorship.

For lift and drag analyses, an aerodynamic profile was built and inserted in the wind tunnel, which is stage 6 of the project. It was decided to build a styrofoam wing with a GÖ387 profile (Göttingen) (KANDIL, 2017; RIEGELS, 1958), which was installed in a device that allows its vertical displacement, as shown in Figure 7.

Figure 7 - Device with aerodynamic profile GÖ387 for vertical displacement.

Source: Our authorship.

In the last stage of Chart 1, with the wind tunnel completely assembled, its accessories installed and the aerodynamic profile ready, an experimental test with air flow in the wind tunnel could be carried out.

Technical Analysis and Governing Equations

Experimental measurements were collected in an airflow test through the wind tunnel, aiming to obtain the flow velocity of the fluid using a Pitot tube. The pitot tube creates a pressure differential from the complete deceleration of the fluid at one of its points. This pressure differential can be used in the energy conservation equation, Eq. (1), developed by Daniel Bernoulli (BRUNETTI, 2008; MUNSON et al., 2009; ROSKAM; LAN, 1997) for speed calculation.

$$\frac{V_1^2}{2} + \frac{p_1}{\rho} + z_1 g = \frac{V_2^2}{2} + \frac{p_2}{\rho} + z_2 g \tag{1}$$

in which V is air velocity, p is air pressure, z is height relative to a reference frame, g is gravity acceleration and ρ is air density. Subscripts 1 and 2 represent two points taken for flow analysis.

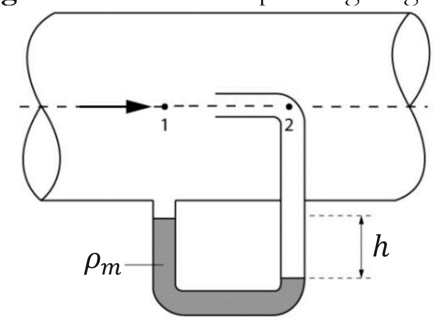
Figure 8 shows the operating diagram of a Pitot tube, which is composed of a "U" shaped tube for taking pressure at two points (1 and 2). The pressures at points 1 and 2 are called static pressure and stagnation pressure, respectively. The velocity at point 2 is zero due to the deceleration of the fluid and the velocity at point 1 corresponds to the airflow velocity. In this case, there is no difference in elevations between points 1 and 2. The parameters ρ_m and h represent, respectively, the density and unevenness of the manometric fluid, which is used to obtain the pressure difference between points 1 and 2 of the flow. The manometric fluid used in the experiment was ethanol and the pressure difference is obtained using manometry. Thus, by algebraically manipulating Eq. (1), the airflow velocity is obtained as follows:

$$V_1 = \sqrt{\frac{2(p_2 - p_1)}{\rho}} \tag{2}$$

$$p_2 - p_1 = gh(\rho_m - \rho) \tag{3}$$

being the difference in level h of the manometric fluid measured in the experiment and being known as the densities of the fluids and the acceleration of gravity.

Figure 8 - Pitot tube operating diagram.

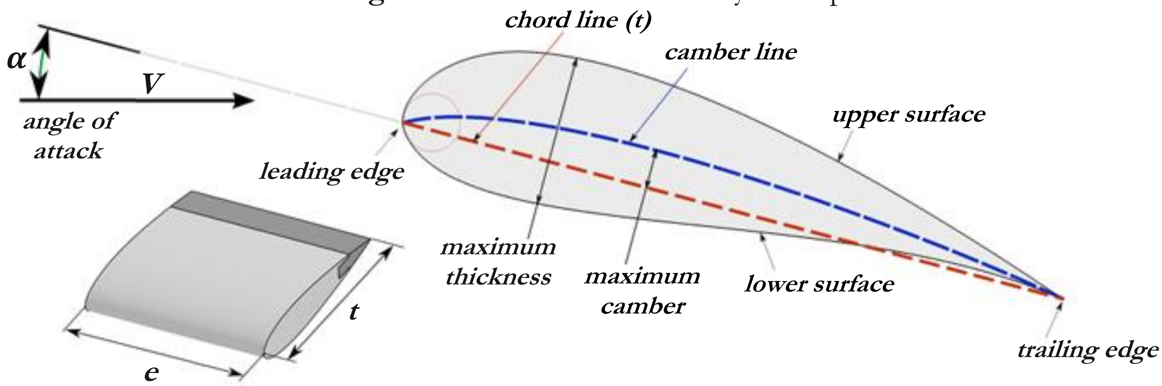


Source: Adapted from Brunetti (2008).

For a better understanding of the relationship between the velocity and pressure of a fluid, the mental experiment validated by Daniel Bernoulli, when he developed the Law of Conservation of Energy for fluids, was proposed to students. This experiment is described in the work *Hydrodynamica* (BERNOULLI, 1738) and was based on the analysis of a reservoir that discharged water through a horizontal tube at its bottom. Through small transformations of this specific configuration, several experimental variants were proposed that were solved through thought experiments. Similarly, this process of mental analysis was used in the wind tunnel, resulting in the application of the Law of Conservation of Energy. Manterola (2015) analyzes and validates Bernoulli's mental experiment, promoting the construction of creation in construction creativity.

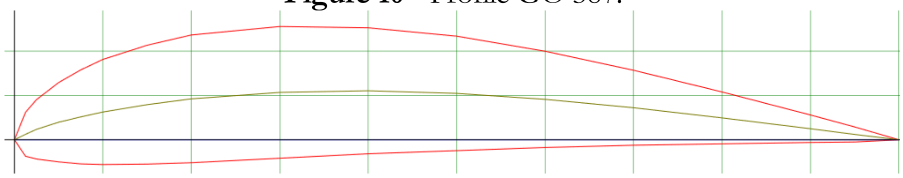
In the aerodynamic analysis of the GÖ 387 profile, the Airfoil Tools software ([n.d.]) was used to generate the profile and obtain the aerodynamic parameters necessary for calculating the lift and drag forces on the profile. This profile was chosen because it is easy to build, as it has a practically straight soffit (lower region). The characteristics of an aerodynamic profile are presented in Figure 9. Figure 10 and Chart 2 show, respectively, the GÖ 387 profile generated in the Airfoil Tools software and the aerodynamic parameters of this profile. Similarly to this study, Araújo et al. (2017) used an application, *Wind Tunnel*, aiming to strengthen the concepts of fluid dynamics on aerodynamic profiles for high school students.

Figure 9 - Features of an aerodynamic profile.



Source: Adapted from Wikimedia Commons (2011).

Figure 10 - Profile GÖ 387.



Source: Airfoil Tools ([s.d.]).

Chart 2 - Aerodynamic parameters of the GÖ 387 profile.

Chord line (t) $[m]$	0.15
Wingspan (e) $[m]$	0.15
Wing area (S) – $(S = t.e)$ $[m^2]$	0.0225

Source: Our authorship.

Based on the aerodynamic parameters obtained, the lift force (F_l) and drag force (F_d) on the profile are calculated as follows (FOX et al., 2018):

$$F_l = C_l \frac{1}{2} \rho V^2 S \quad (4)$$

$$F_d = C_d \frac{1}{2} \rho V^2 S \quad (5)$$

in which V is the air velocity in the test area of the tunnel, obtained according to Eq. (2). The parameters (C_l) and (C_d) are, respectively, the lift coefficient and the drag coefficient in the profile, which are obtained using the Airfoil Tools software ([s.d.]) from the knowledge of the Reynolds number (Re) of the airflow over the profile, Eq. (6). The Reynolds number is a dimensionless parameter that allows checking the stability of the flow. To calculate the Reynolds number, it is necessary to obtain the flow velocity in the tunnel from the experimental test.

$$Re = \frac{\rho V t}{\mu} \quad (6)$$

in which μ is the dynamic viscosity of the air.

The aforementioned concepts about air dynamics were evaluated as an educational process by Eastlake (2006), emphasizing the fact that they make sense for audiences of different levels. Although the origin of the concepts encompasses mathematical complexity, Eastlake (2006) infers that it is possible to describe the phenomenon in a simplified way, adequate to the student's level.

RESULTS and FIND OUTS

Perceptions about pedagogical practice

The perceptions about the pedagogical practice were listed from the discussions in the focus group, being grouped into topics according to the previously established points to be investigated in this didactic proposal.

Regarding the evaluation of learning from the development of the project, some positive effects were observed:

- There was effective participation and interest of the students working on the project, including pertinent questions linked to prior knowledge of the content addressed;
- The existence of an experimental test in the project is a motivation and incentive for not giving up on the activity, a fact that, according to the students, could have occurred due to the mathematical complexity inherent to the test;
- The need to use several laboratories for the construction of the wind tunnel contributed to greater resourcefulness and practical ability in handling machines and equipment that students expect to have close contact with when they enter the job market;
- The joint action of the students in solving problems and transposing the stages of the project favored the exchange of ideas and the ability to organize for the execution of the whole;
- Carrying out the experimental test together with the mathematical calculations linked to it broadens the view of the need for a chain of actions for the success of the activity;
- The ambiance and dynamism for the development of the project lead to a more relaxed atmosphere than the classroom, contributing to the exposition of doubts and presentation of opinions and points of view in a more uninhibited way;
- The vision and understanding of how to use technical concepts and apply mathematical equations is significantly expanded in the development of a project with experimental tests.

Regarding the integration between contents from different disciplines and interdisciplinarity in the project, findings were also listed. Chart 3 shows the disciplines and contents of the course that are part of the wind tunnel construction project, in addition to relating them to their applicability in the project.

Chart 3 - Disciplines, contents, and applicability in the project.

Disciplines	Contents	Applicability
Mechanical Technical Drawing and Metrology	Terminology and the metric system, unit conversion, instrumentation, and drawing reading	Wind tunnel design and drawing
Basic Electricity	Voltage, current, and circuits	Installation of the electric motor and the LED bus in the tunnel
Applied Electronics	Power devices	Electric motor speed control
Physics	Electricity	Installation of the electric motor and the LED bus in the tunnel

Hydraulics and Pneumatics	Fluid mechanics	Installation of the Pitot tube, measurement of the pressure differential, construction of the aerodynamic profile, and carrying out the experimental test
Portuguese Language and Literature	Grammar, writing, and dissertation	Bibliographic research and writing of a technical report
Mathematics	Functions and Operations	Mathematical calculations
Machining Practice	Manufacturing and machining processes	Confection of the aerodynamic profile and construction of the constituent parts of the tunnel
Programming Applied to Mechatronics	Algorithms, flowcharts and programming logic, communication with peripherals	Writing programming code in C language and communication with Arduino
Integrative Project in Mechatronics	Skills for research and group work	Bibliographical research, integration of acquired knowledge, and organization for project development
Resistance of Materials and Machine Elements	Dimensioning of components and normalized elements	Construction of the constituent parts of the tunnel
Microcontrollers	Architecture and features of a microcontroller system	Compilation of the program in C language, reading, and data acquisition by Arduino
Materials technology	Work safety and mechanical properties	Appropriate use of laboratories, acquisition of materials, preparation of the aerodynamic profile, and construction of the constituent parts of the tunnel

Source: Our authorship.

Based on Chart 3, prior knowledge of 43% of the subjects in the curriculum of the Technical Course in Mechatronics Integrated to High School at IFSP Campus Catanduva was necessary for the execution of the project. Of this total of disciplines, 77% were from the professional area. Pierson and Neves (2001) report that students often do not see the connection between the disciplines studied and a work that covers course concepts, promoting integration as a possibility to make this connection, as defined. Chart 3 was built from the focus group with the effective participation of students, showing that the visualization of the connection between disciplines and projects is possible.

Aiming at the occurrence of interdisciplinarity in the pedagogical practice, the professors maintained an instigating posture towards the students throughout the entire development of the project, based on constant conversations and discussions of the events. The professors sought to maintain guiding conduct with a dialogic perspective, articulating the contents of the disciplines with the experimental essay and aiming, based on their attitudes, at a greater engagement in the students' learning through new relationships between the project executors. The following points were raised in the focus group on content integration and interdisciplinarity in the project:

- Learning doubts about certain content, transmitted only via theoretical explanation by the professor, can be resolved by interacting with other content inserted in experimental practice and also via discussion with another student participating in the project;
- The construction of the wind tunnel and the carrying out of the experimental test enabled us to understand how different contents can be used simultaneously and interconnected with each other, facts that are often not visualized in the theoretical explanation of the professor;
- The experimental test allowed the physical manipulation of different contents through the direct observation of events, unlike what happens inside the classroom, where the student passively receives the contents in a fragmented way;

- The form of presentation, sequential and structured, of some contents in textbooks, which was not understood by the students, started to have meaning after carrying out the project and the experimental test;
- Contents with a degree of abstraction, in the students' understanding, can be materialized by the development of the project with experimental tests;
- The experimentally verified contents and the connection between them become peremptory in the students' memory, facilitating the use of the concepts in the future;
- The development of the project and the carrying out of the experimental test enabled the students to have greater reasoning ability to recognize the need for simultaneous application of contents, as well as the relationship between them in real projects;
- The visualization of the connection between the contents and the dependence between them in certain situations is facilitated by the posture and inciting attitude of the professor, in which they aim to stimulate the students' reasoning and perception for the construction of cognitive intelligence.

Difficulties by the students in the development of the project and in carrying out the experimental test were listed in the focus group. In the way the project was conducted, the difficulties were fundamentally related to its technical part, with emphasis on:

- Use of machines and tools available in the mechanical fabrication laboratory due to some parts of the project having a higher degree of construction complexity than the didactic elements built in the classes and subjects of the course;
- Adaptation to the constant need to use Personal Protective Equipment (PPE) within laboratories and follow the strict safety standards of a mechanical workshop (NR 6 - SECRETARIA DO TRABALHO, [n.d.]);
- Recurrent project feasibility analysis and verification of discrepancies during execution, promoting adaptability and the search for solutions, not only mechanical and electronic but also economically viable;
- Bibliographic research and handling databases.

Based on all the perceptions and inquiries that were raised in the focus group, the participating teachers and mediators of the pedagogical practice were able to establish a posteriori general considerations about the activity:

- The proposed didactic practice showed that students are sensitive to learning when they are subjected to external stimuli, deviating from traditional learning methodologies in vocational education;
- The development of the project with an experimental test provides an indication that the activity carried out, added with adaptive transformations in search of improvements in this teaching-learning process, has the potential to be legitimized as a mediating element in the learning of concepts on air dynamics. In this context, the activity encourages the student to cooperate in the construction of both his knowledge and the learning acquisition process, inquiring about the physical phenomenon from the survey and verification of his hypotheses;
- The project carried out leads to the revisiting of teaching-learning concepts in the professionalizing sphere, opening reflection on the current primacy of teaching technical concepts transmitted exclusively in the classroom space;
- The dialogical approach of the professors throughout the project allowed mapping of previous misconceptions of the students, providing opportunities for specific interventions to dissolve theoretical inconsistencies. This aspect, associated with the experimental and problematized practice, allowed participating students to reinterpret ambiguous concepts or whose understanding was inaccurate;

- The relationships that are established between the student as a speculative subject and the object of analysis became explicit with the development of the project, as opposed to traditional technical teaching within the classroom, in which these relationships tend to be implicit;
- The inherent versatility of the process of executing the activity allowed the didactic manipulation by the professors at appropriate moments of practice, compelling the students to carry out the learning process. Thus, it is evident that the teacher's intervention tends to generate positive effects when shaped according to the circumstances;
- The developed activity explained to the students that the physical principles linked to the dynamics of the air are in line with natural processes, conforming the theoretical framework to events of the same category observed in nature.

The development of the project with an experimental test simultaneously addressed the qualitative and quantitative aspects of learning. At the same time that it constituted a practice governed by teaching manipulation focusing on the verification of physical phenomena and cognitive development, it allowed the sharing of parameters and the definition of a categorical metric for the technical-mathematical-experimental procedure, aiming at the performance of the student in the labor market. Qualitative and quantitative analyzes are at the forefront of similar works in the area of exact sciences (such as Physics and Chemistry) found in the literature, but in a segregated way, leaving a gap that makes a simultaneous assessment of this duality impossible. From this point of view, the solid and comprehensive training of technical education students is likely to remain at the back of the educational process.

For the professional performance of a mechatronics technician, it is not enough to understand the physical phenomenon. It is necessary to be able to link ideas with the proper assumptions for the success of the action, presenting procedure and results with criticality and plausibility. The experience of vocational education teachers has shown that the simple transmission of knowledge in the classroom, as well as reproductive empiricism in experimental practices, do not constitute didactic options capable of prioritizing the completeness of learning for students. The simultaneous focus, qualitative and quantitative, addressed in this project can be considered a manifestation of the possibility of thorough learning. In addition, the results presented in this pedagogical practice may support analyzes of works similar to this one, allowing more reliable reproductions and resulting comparisons of results.

Based on the above, the development of the project with an experimental test can contribute to the improvement of the teaching-learning process, allowing students to interconnect and assimilate more forcefully, contents and disciplines ruled by thought-provoking discussions orchestrated by teaching attitudes and intentions. It should be noted that this project is not a solution to the learning difficulties observed in the classroom, nor does it intend to do so. It is a pedagogical and experimental essay in search of the intensification and fixation of the learning of technical concepts transmitted in a technical course in mechatronics integrated into the high school of the Federal Institute of São Paulo, as well as, it seeks to bring the student closer to real work situations, because, as asserted by Berbel (2011), the pedagogical environment can provide freedom and autonomy in the decisions of the future professional.

Experimental Test and Technical-Mathematical Results

For the experimental test in the wind tunnel, the values from Chart 4 were used for the acceleration of gravity (g), the density (ρ) of the air, the dynamic viscosity (μ) of the air, and the density of ethanol (ρ_m) (manometric fluid in Pitot tube). Data on air properties were extracted from Bergman and Lavine (2019) and ethanol density was calculated using The Engineering ToolBox (2021), all properties considering normal conditions of atmospheric pressure and temperature of 20 °C.

Chart 4 - Parameters used in the experimental test.

Gravity acceleration (g) $[m/s^2]$	9.81
Air density (ρ) $[kg/m^3]$	1.194

Dynamic air viscosity (μ) $[Pa.s]$	$1.81 \cdot 10^{-5}$
Ethanol density (ρ_m) $[kg/m^3]$	789.4

Source: Our authorship.

The wind tunnel was subjected to air flow and the height difference h of the manometric fluid in the Pitot tube was measured. Thus, the velocity V of the flow was obtained from Eqs. (2) and (3) and the Reynolds Re number calculated by Eq. (6). The value obtained for Re was used as input data in the Airfoil Tools software to obtain the lift (C_l) and drag (C_d) coefficients on the GÖ 387 profile, and the values obtained for these coefficients constitute the condition of better glide and higher profile efficiency. With the lift and drag coefficients in hand, the lift (F_l) and drag (F_d) force values were calculated using Eqs. (4) and (5). Chart 5 shows the values obtained for the aforementioned parameters.

Chart 5 - Parameters obtained from the experimental test.

Slope (h) $[m]$	0.007
Air Speed (V) $[m/s]$	9.52
Reynolds number (Re)	$9.42 \cdot 10^4 \approx 10^5$
Lift Coefficient (C_l)	1.1151
Drag Coefficient (C_d)	0.02217
Lift force (F_l) $[N]$	1.358
Drag force (F_d) $[N]$	0.027

Source: Our authorship.

The Airfoil Tools software allows the simulation of airfoils with some preset options for the Reynolds number as integers. For this reason, the Reynolds number obtained in Chart 5 was approximated in form $Re = 9.42 \cdot 10^4 \approx 10^5$ to obtain lift and drag coefficients. From the Reynolds number, the Airfoil Tools software also provides, in addition to the coefficients for the best efficiency of the profile, the angle of attack (α), Fig. 9, for this condition, whose value is $\alpha = 6.25°$.

The experimental test added to the mathematical analysis of the dynamics of the air inside the wind tunnel allowed the students to better understand the concepts that govern the physical phenomenon. The visualization of the phenomenon contributed to the clarification of the effects of the variables intrinsic to the problem, proving what was prescribed by the governing equations. In this process, the construction of the concept of pressure difference can be highlighted, observed in the Pitot tube to obtain the air velocity in the tunnel and also in the phenomenon of support, given by the pressure difference between the lower surface (lower region) and the upper surface (upper region) of the airfoil.

FINAL CONSIDERATIONS

The development of the wind tunnel project with experimental testing proved existing theories on air dynamics and brought students closer to the universe of applied science. Mathematical and physical concepts of aerodynamic forces linked to aircraft flights and aerodynamics in vehicles could be demonstrated through a proactive and motivating activity, in which students were immersed in a laborious practice of knowledge construction, that is, not merely accepting information passively.

Analyzing the development of the project as a pedagogical practice, we found that this didactic format can positively contribute to the teaching-learning process. The dialogue between professors and students was expanded and the visualization of the link between theoretical subjects addressed in the course and their applicability in a real experimental situation was clarified, which allowed students to externalize their previous knowledge for the re-signification of contents. Carrying out the project also helped to break learning limits concerning the understanding of technical-mathematical concepts sometimes seen with a certain degree of complexity and without an apparent link with reality, a fact that characterizes the practice as a liberating action for the construction of knowledge by introducing more favorable conditions for cognitive exercise.

Based on the teaching actions and instigations, the experimental essay facilitated the manipulation of different contents by the students, as well as the perception of integration between them, providing a holistic view of what is usually fragmented in the usual didactic processes within the classroom. We observed that the knowledge acquired in this way is preserved in the student's memory for future applications. The dialogical approach throughout the project aimed to favor the creation of meaning for the contents and the occurrence of interdisciplinarity. Many studies address and conceptualize interdisciplinarity, providing guidelines for it to occur. However, examples of how to perform interdisciplinary activities in an integrated technical course focusing on air dynamics are not found. The practice carried out shows that it is possible to cooperate to fill this gap, giving evidence that interdisciplinarity, beyond the simple integration between disciplines and contents, can be achieved.

This pedagogical proposal sought to transpose the existing parallelism between the analysis of didactic practice (qualitative focus) and technical-mathematical investigation (quantitative focus) commonly found in the literature in works with experimentation in the area of exact sciences. Aiming at a simultaneous and integrated analysis, in the development of the project, an effort was made to highlight the mathematization of the problem and its technical procedure beyond a simple script and verification of laws, incorporating taking actions to obtain data, applying governing equations and presenting results, together with the verification of intellectual aspects during the activity, which includes assimilation and integration of contents, the connection between theory and practice, added to the awakening of curiosity and decision-making by the students.

The investigative and dynamic nature of the activity, going beyond traditional classroom teaching, was essential to provide students with opportunities to raise hypotheses and analyze scientific arguments. How the professor intermediates the unfolding of the practice, aiming to keep the students' interest and attention sharp, is also extremely important for the success of the work. It is through teacher mediation that a possible simple and scripted empiricist practice is added with a speculative nature, becoming appropriate for the construction of knowledge with scientific rigor and pleasure for the result achieved. In this context, we highlight the indispensability of teacher training in the technical and pedagogical spheres to work on the project, including substantial changes in conventional teaching practices for the management and design of the activity. Continuing education is essential for teachers to increase their perceptions of pedagogical actions and revisit their teaching concepts in search of an increasingly polyvalent and multifaceted profile.

The methodological proposal of the wind tunnel was not intended to replace the traditional teaching applied in the technical course integrated into high school, but to be an additional instrument to encourage and enrich the teaching-learning process. There is no specific form for carrying out the pedagogical proposal. The regency and procedures for carrying out the practice can and need to be improved. Experimenting with variations in the way of acting, as well as the use of alternative praxis, can further enhance learning in project development with experimental testing.

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Both authors had active participation in all stages of the project.

CONFLICT OF INTEREST DECLARATION

The authors declare that there is no conflict of interest with this article.