v. 4, n. 7, 2024

Journal of
Engineering
Research

FOSTERING PRACTICAL ENGINEERING SKILLS THROUGH PROBLEM-BASED LEARNING: A SCISSOR LIFT DESIGN AND AUTOMATION CASE STUDY

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Abstract: This technical article introduces a pioneering educational approach that seamlessly melds Problem-Based Learning (PBL) with the practical development of a small-scale scissor lift. Encompassing the realms of design, simulation, and automation, the project offers students an immersive learning experience within the framework of a Machine Design course. By engaging in the conceptualization, design, prototyping, and automation of the scissor lift, students gain invaluable insights into the multifaceted dimensions of engineering practice. Problem-Based Learning serves as the foundational pedagogical strategy, encouraging students to collaboratively tackle real-world engineering problems. The scissor lift project becomes a microcosm of the engineering process, fostering critical thinking, teamwork, and communication skills. From the initial ideation and iterative design refinement to the application of Finite Element Analysis (FEA) to assess structural integrity, students learn to navigate challenges that mirror authentic engineering scenarios. The article delves into the pivotal role of simulation in refining the design's performance. By employing FEA tools, students gain competence in predicting mechanical behaviors, optimizing load distribution, and ensuring operational safety. The practical aspect of the project materializes during the prototyping phase, where theoretical designs transform into tangible prototypes. Load testing and iterative adjustments further imbue students with a hands-on understanding of engineering intricacies. Highlighting the contemporary relevance of automation, the project extends beyond conventional mechanical considerations. Arduino-based automation injects the element of control and precision into the scissor lift's operation. Students integrate sensors, actuators, and microcontrollers, thereby aligning their

learning with the evolving landscape of engineering technologies. The article not only showcases the symbiotic fusion of PBL and practical engineering in the context of scissor lift design and automation but also underscores the broader significance of experiential learning. By immersing students in a project that transcends theoretical confines, educators can cultivate engineers equipped with the acumen to navigate real-world challenges and innovations.

Keywords: Problem-Based Learning, Scissor Lift Design, Finite Element Analysis, Automation, Engineering Education, Experiential Learning.

INTRODUCTION

The realm of engineering education is in a constant state of evolution, driven by the dynamic demands of modern industry and technology. In this context, the integration of theoretical knowledge with practical skills stands as a paramount objective. This article embarks on a journey that delves into a novel pedagogical approach, merging the principles of Problem-Based Learning (PBL) with the tangible intricacies of engineering design, simulation, and automation. Through a comprehensive case study centered around the creation of a small-scale scissor lift, this article sheds light on the transformative power of experiential learning within the domain of mechanical engineering.

The conventional classroom landscape, with its emphasis on theoretical lectures and standardized assessments, often presents a divergence from the real-world challenges encountered by engineers. PBL emerges as a beacon of innovation, advocating for a student-centric approach where active engagement, critical thinking, and collaborative problem-solving reign supreme. In the context of engineering education, PBL empowers students to navigate complexities akin to those encountered by practicing engineers, fostering a holistic skill set that extends beyond theoretical comprehension.

The focal point of this article's exploration is the design and automation of a small-scale scissor lift. This project serves as a canvas upon which the principles of PBL are vividly portrayed, intertwining theoretical concepts with hands-on implementation. Under the purview of a Machine Design course, students embark on a semester-long journey to conceive, design, simulate, prototype, and ultimately automate a functional scissor lift model. This comprehensive endeavor encapsulates the quintessence of engineering practice, bridging the gap between academic theory and tangible innovation.

The scissor lift project's iterative nature underscores the inherent complexity of engineering design. From the inception of initial sketches to the creation of detailed Computer-Aided Design (CAD) models, students grapple with multifaceted considerations. Each phase of the project necessitates critical decision-making, where design choices are weighed against performance benchmarks, material constraints, and safety protocols. This iterative journey mirrors the unpredictable landscape of real-world engineering, nurturing adaptive thinking and resilience.

As this article unfolds, it will traverse the intricate stages of the scissor lift project, providing an in-depth exploration of the design process, the role of Finite Element Analysis (FEA) in structural simulation, the transition from virtual models to physical prototypes, and the integration of Arduino-based automation. Through these successive chapters, the multifaceted facets of engineering education come to life, demonstrating how the amalgamation of theory and practice creates engineers prepared to face the challenges of tomorrow.

In essence, this introduction sets the

stage for an expedition into the innovative intersection of Problem-Based Learning, mechanical design, simulation, and automation. Through the exploration of the scissor lift project's journey, readers will gain insights into the transformative potential of experiential learning and its enduring impact on engineering education.

LITERATURE REVIEW

The fusion of Problem-Based Learning (PBL) principles with hands-on engineering projects has garnered considerable attention within the realm of engineering education. This chapter explores the existing body of literature that underscores the significance of integrating experiential learning with the theoretical foundations of mechanical engineering.

PROBLEM-BASED LEARNING: A CATALYST FOR ACTIVE LEARNING

Problem-Based Learning has established itself as a potent pedagogical strategy that fosters active student engagement, critical thinking, and collaborative problem-solving. In the context of engineering education, PBL transcends the traditional lecture-based format, propelling students into the role of proactive problem solvers. This approach not only aligns with the multifaceted challenges encountered in engineering practice but also nurtures skills that extend beyond subject-specific knowledge.

Numerous studies highlight the efficacy of PBL in engineering education. Smith (2005) emphasize that PBL cultivates a deep understanding of concepts and enhances retention compared to conventional methods. The adaptability of PBL across disciplines, as demonstrated by Saimon, Lavicza and Dana-Picard (2022), underscores its potential as a transformative tool for developing critical skills.

EXPERIENTIAL LEARNING IN ENGINEERING DESIGN

The integration of hands-on experiences within engineering curricula has proven instrumental in bridging the gap between theory and practice. Experiential learning provides students with a tangible platform to apply theoretical knowledge in real-world scenarios. As asserted by Chan (2012), experiential learning is a cyclical process involving concrete experience, reflective observation, abstract conceptualization, and active experimentation. In the context of mechanical engineering, several studies emphasize the importance of experiential learning.

Chant, Moes and Ross (2022) advocate for practical projects that cultivate problem-solving skills and creative thinking. Furthermore, Shekar (2014) emphasize that hands-on projects provide students with a deeper understanding of engineering principles and encourage lifelong learning.

AUTOMATION AND INNOVATION IN ENGINEERING EDUCATION

The increasing prevalence of automation in engineering systems underscores the importance of preparing students for an evolving technological landscape. Integrating automation projects within engineering education serves to expose students to contemporary tools and methodologies (FAGERHOLM *et al.*, 2017). Arduino-based projects, in particular, have gained prominence due to their user-friendly interface and versatility (OCAK, 2018).

Research by Diefes-Dux *et al.* (2004) underscores the transformative impact of integrating Arduino-based projects in engineering education. Such projects not only enhance students' understanding of automation concepts but also provide them with a platform to explore interdisciplinary applications. Additionally, studies by Henriksen *et al.* (2018) emphasize the potential of automation projects to foster innovation and creativity among students.

SYNTHESIS OF LITERATURE AND RESEARCH GAP

While existing literature, as asserted by Ngereja, Hussein and Andersen (2020), establishes the efficacy of PBL, experiential learning, and automation projects in engineering education, there remains a scarcity of in-depth case studies that intricately intertwine these facets. The scissor lift project presented in this article bridges this gap by providing a comprehensive case study that encompasses the design, simulation, prototyping, and automation of a mechanical system. By doing so, this article contributes to the existing body of knowledge by offering a holistic perspective on the integration of experiential learning principles within a mechanical engineering context.

In summary, the synthesis of literature highlights the transformative potential of Problem-Based Learning, experiential learning, and automation projects in engineering education (CHEN *et al.*, 2020). The scissor lift project emerges as a unique endeavor that amalgamates these principles, serving as a beacon of innovation and hands-on learning.

METHODOLOGY

The successful integration of PBL, engineering design, simulation, and automation within the context of the scissor lift project hinges upon a structured methodology. This chapter provides an in-depth overview of the sequential steps undertaken to achieve the project's multifaceted objectives.

PROJECT INITIATION AND PROBLEM DEFINITION

The scissor lift project commences with an elucidation of the overarching objectives and challenges. Students are introduced to the concept of PBL, wherein they collaboratively define the problem statement, identify project requirements, and establish measurable goals. This phase cultivates teamwork, problem-solving skills, and the ability to translate theoretical concepts into practical contexts (YU; FAN; LIN, 2014).

CONCEPTUALIZATION AND DESIGN

The design phase encapsulates ideation, conceptualization, and the creation of initial design sketches. Drawing inspiration from engineering principles and creative problem-solving, students generate diverse design concepts. These concepts are iteratively refined, considering factors such as load-bearing capacity, stability, ergonomics, and material selection. Computer-Aided Design (CAD) software is employed to translate concepts into detailed virtual models (WHYTE *et al.*, 2000).

FINITE ELEMENT ANALYSIS (FEA) SIMULATION

Finite Element Analysis serves as a pivotal tool in assessing the structural integrity of the scissor lift design. Virtual simulations are conducted using FEA software to analyze stress distribution, deformation, and failure points under varying load conditions. This phase instills proficiency in simulation methodologies and reinforces the importance of validating design choices through numerical analysis (KUDELA; MATOUSEK, 2022).

PROTOTYPING AND TESTING

The virtual designs are materialized through prototyping. Students fabricate

Journal of Engineering Research ISSN 2764-1317 DOI: https://doi.org/10.22533/at.ed.3174724260210

physical models using suitable materials and manufacturing techniques. Load testing is conducted to validate the designs' load-bearing capabilities and operational safety. Feedback from testing informs iterative design adjustments, illustrating the bridge between theoretical modeling and real-world performance (SASS; OXMAN, 2006).

INTEGRATION OF AUTOMATION WITH ARDUINO

Automation is introduced as an innovative extension of the scissor lift project. Students learn to integrate sensors, actuators, and microcontrollers through Arduino-based platforms (VOSTRUKHIN; VAKHTINA; BONDAR, 2017). This phase encapsulates programming, circuit design, and interfacing, enabling students to automate the scissor lift's operation. The project thereby evolves beyond mechanical design, aligning with contemporary engineering paradigms.

REFLECTION AND CONTINUOUS IMPROVEMENT

The methodology concludes with a phase of reflection and continuous improvement. Students assess the project's successes, challenges, and lessons learned. This reflective exercise reinforces the iterative nature of engineering and imparts the importance of embracing failures as learning opportunities. The insights gained inform future projects and underscore the enduring impact of experiential learning (JAMISON *et al.*, 2022).

In summary, the methodology adopted for the scissor lift project exemplifies a cohesive integration of PBL, engineering design, simulation, and automation. This structured approach empowers students to navigate complex engineering challenges while nurturing skills essential for modern engineering practice (KRAWCZYK, 2016).

RESULTS AND DISCUSSIONS

The elevating scissor platform developed by a group of students is equipped with a manual crank-driven mechanism, showcasing the conversion of rotational motion into a precise linear translational movement. Through this ingenious mechanical arrangement, the rotational input provided by the crank initiates the translation of a motion to an advancing or retracting trajectory along a transmission screw. Consequently, this linear motion is harnessed to propel a mobile pin situated within the interconnected beams of the scissor structure. The model is depicted in Figure 1.

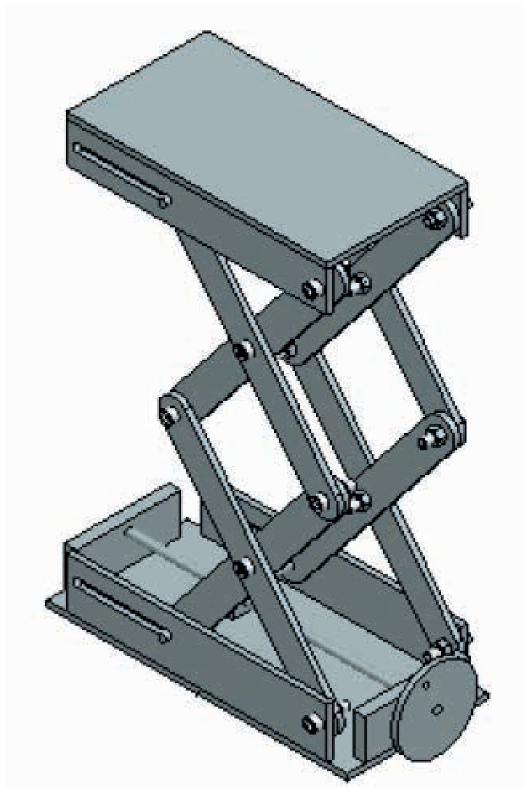

Figure 1 – Elevating scissor platform 3D model constructed in NX Siemens

To illustrate this intricate process in action, consider the scenario of load elevation. As the mobile pin responds to the rotational energy from the crank mechanism, a sequential series of interconnected beams orchestrates a synchronized "scissor" movement. In this orchestrated choreography, the angular disposition of these beams progressively adjusts, inducing an incremental shift in their respective inclinations (DONG *et al.*, 2012).

The culmination of this orchestrated motion yields an ascending trajectory, wherein the interconnected beams progressively extend to greater inclinations. This incremental adjustment continues until the zenith is attained—marked by the point where the maximum inclination is reached. Notably, this peak inclination corresponds directly to the juncture of highest load elevation within the defined operational scope of the platform (CIUPAN; CIUPAN; POP, 2019).

In essence, the interplay of the crank mechanism, the transmission screw, and the interconnected beams orchestrates a harmonious dance of mechanical energy conversion. This intricate orchestration achieves the transformation of rotary input into linear elevation, embodying the core essence of this scissor lift platform's operational principle (PAN *et al.*, 2017).

PROTOTYPING

The exploded view presented in Figure 2 showcases a comprehensive breakdown of the structure, accompanied by meticulous identification of each individual component. This detailed visual representation offers a panoramic insight into the intricate arrangement of parts, contributing to a profound understanding of the assembly's composition.

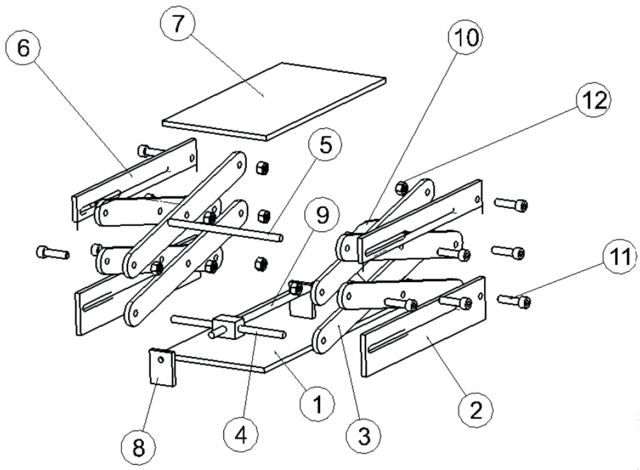

Figure 2 – Elevating scissor platform model exploded view

In conjunction with the exploded view, a comprehensive list of components, shown in Table 1, further elucidates the construction, enabling a comprehensive grasp of the assembly's intricate makeup.

Item	Description	Quantity
1	Lower Base	1
2	Lower Guide	2
3	Beam	8
4	Mobile Rod	1
5	Fixed Rod	1
6	Upper Guide	2
7	Upper Base	1
8	Support	2
9	Screw Shaft	1
10	Handle	1
11	M8X30 Screw	12
12	M8 Nut	12

Table 1 – Elevating scissor platform model list of components

The prototype depicted in the Figure 3was successfully fabricated.

Figure 3 – Elevating scissor platform prototype

The assembly process of the prototype commenced with the lower guide, followed by the arrangement of support beams, and subsequently, the placement of the upper guide. Finally, the guide pin was added to complete the assembly. The individual components utilized in constructing the prototype are visually detailed from Figure 4 to Figure 9.

Figure 4 – Upper guide of the prototype structure in MDF

Figure 5 – Lower guide of the prototype structure in MDF

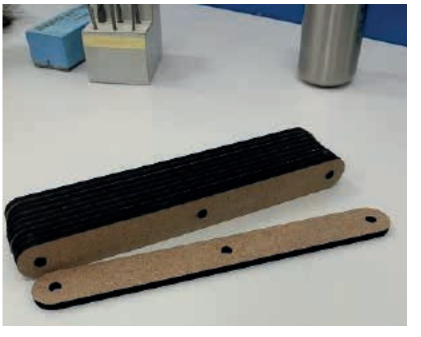

Figure 6 – Beams of the prototype structure in MDF

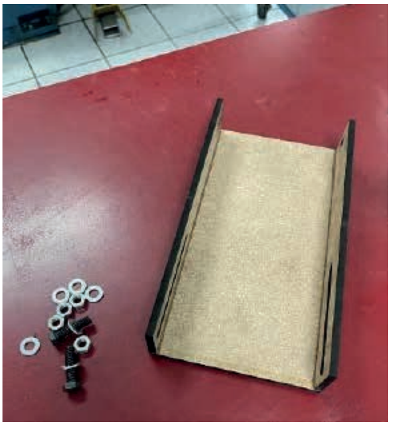

Figure 7 – Partial assembly of the upper base with the upper guides and demonstration of the screws, nuts, and washers used in the assembly

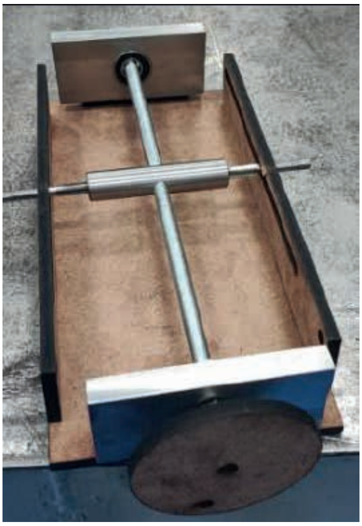

Figure 8 – Machined components of the prototype

Figure 9 – Final stage of prototype assembly

FINITE ELEMENT ANALYSIS

The structural analysis of the lift platform model was conducted through the rigorous framework of finite element analysis (FEA). This approach involves discretizing the geometry into finite-sized elements, each possessing distinct behaviors, thereby effectively approximating the continuous behavior of the entire structure (ROYCHOWDHURY; DODDS, 2003). The simulation process, as described herein, was executed employing the advanced engineering software, Altair® Inspire™, an industry-standard solution renowned for its prowess in structural optimization (FEREDE, 2020).

Commencing with the importation of the meticulously designed geometry from Siemens NX software, the study centers on a pivotal operational phase of the platform when it reaches a critical extension, approximately threefold its initial dimension, marked by an elevation of around 450 mm. This situation is shown in Figure 10.

Figure 10 – Model made in finite elements showing loads and constraints

In this pivotal configuration, the structural components were securely fastened, and their degrees of freedom intentionally constrained to mirror the real-world assembly scenario.

Given the diverse array of materials and established knowledge concerning MDF behavior housed within its repository, Altair® Inspire™ undertakes a sophisticated material selection process. Stainless steel (AISI 304), chosen for its congruence with MDF properties, was embraced as the structural material. The material properties were tailored, involving a reassignment of the axial

Journal of Engineering Research ISSN 2764-1317 DOI: https://doi.org/10.22533/at.ed.3174724260210

elastic modulus (E) to 2.5 GPa. This calibrated congruence, while not impeding accuracy, substantiates the applicability of the structural analysis results (AHMED *et al.*, 2020).

The design of the lift platform, grounded in precise engineering requirements, engenders the capability to raise an anticipated load of approximately 2 kg. This design criterion serves as the basis for the analytical undertaking, accentuating the practical relevance of the simulation outcomes.

The Altair® Inspire™ software orchestrates the simulation through an intricate sequence of steps. Upon geometry importation and judicious imposition of loads and constraints, Altair® Inspire™ synergizes with auxiliary software entities. This synergy encompasses SimLab, harnessed for mesh generation characterized by optimal element distribution. The meticulous meshing is inherently pivotal for an accurate representation of the geometry's intricate details. Subsequently, the simulation progresses to the processing stage, which is managed by BatchMesher—a utility seamlessly integrated with OptiStruct, designated for elucidating complex structural behavior (HARSHWARDHAN *et al.*, 2022).

The meshing strategy employs triangular elements, colloquially referred to as 'trias' elements, each boasting a nominal dimension of 10 mm. The meshing approach, deliberately calibrated for optimal fidelity, inherently obviates the need for subsequent refinement. The finite element mesh used in this study is shown in Figure 11.

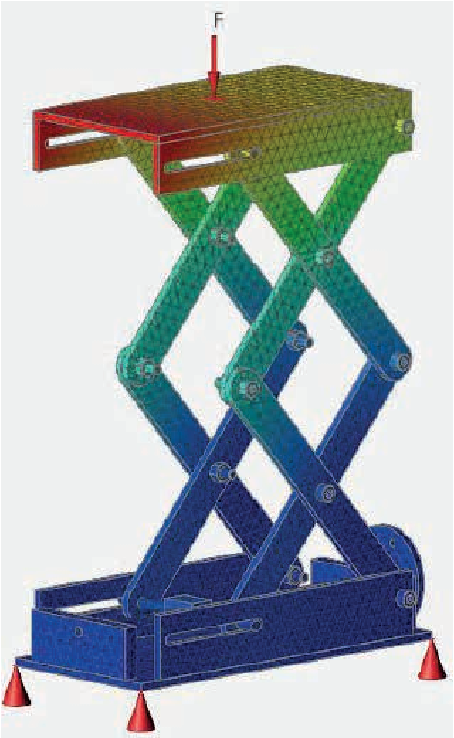

Figure 11 – Platform finite elements mesh

In concurrence with the principles of static analysis, the foundational underpinning of the model necessitates the lower base to be fixed, mitigating translational and rotational degrees of freedom.

It is evident that utilizing steel as the guiding material in the Altair® Inspire™ software yields robust resistance properties. This, coupled with the platform's meticulous design, engenders simulation results characterized by minimal deformation and displacement values. Notably, the regions experiencing heightened deformation and displacement are concentrated within the guides constituting the "scissor" mechanism. This observation is intrinsically logical, as this specific zone shoulders the primary load during the lifting phase.

In the context of finite element analysis a displacement plot is a graphical representation that illustrates the magnitude and direction of the displacements experienced by various points or elements within a structure under

Journal of Engineering Research ISSN 2764-1317 DOI: https://doi.org/10.22533/at.ed.3174724260210

the influence of applied loads or boundary conditions. It is a visualization tool that provides insights into how the structure responds to external forces and constraints (PIETRUSZCZAK; MRÓZ, 1981).

In a displacement plot, each point or element is represented by an arrow or vector that indicates the displacement magnitude and direction. The length of the arrow represents the magnitude of displacement, while its orientation indicates the direction of movement. Displacement plots are typically depicted using a color scale to visualize the intensity of displacement at different locations within the structure (BORST *et al.*, 1993).

Displacement plots are valuable in FEA because they allow engineers and analysts to assess how a structure deforms under different loading conditions. By examining displacement patterns, engineers can identify regions of high deformation or stress concentrations, helping to optimize the design, assess structural integrity, and ensure that the structure can withstand the anticipated loads (ORTIZ; LEROY; NEEDLEMAN, 1987). The displacement plot is presented in Figure 12.

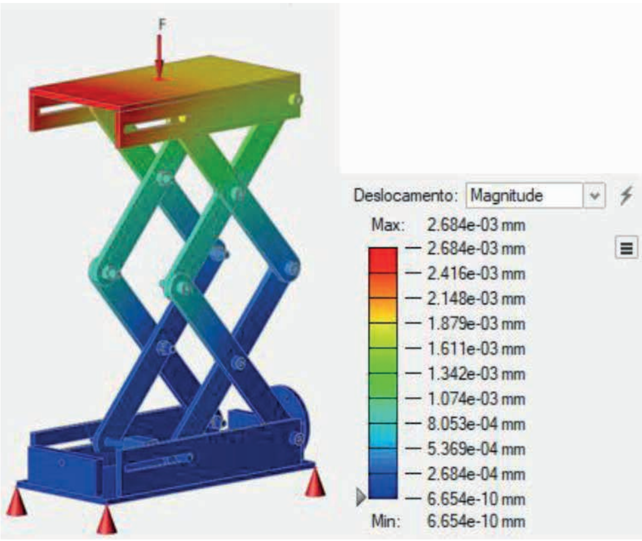

Figure 12 – Lifting platform displacement plot

A plot of main deformations, often referred to as a "Principal Deformation Plot," provides a graphical representation of the primary deformations experienced by a structure under the influence of applied loads or constraints. This plot offers insights into the changes in shape and size of different points or elements within the structure, highlighting the most significant deformation directions and magnitudes (ZHENG; LIU; LI, 2005).

Principal deformations are derived from the eigenvectors and eigenvalues of the deformation tensor, a mathematical representation of the deformation gradient at a given point in the structure. These eigenvectors represent the directions along which the material is stretching or compressing the most, and the corresponding eigenvalues denote the magnitude of deformation along those directions (BABUŁKA; OSBORN, 1987).

In a principal deformation plot, the deformation at each point is represented by a set of vectors, with each vector aligned along one of the principal deformation directions. The length of the vector corresponds to the magnitude of deformation, and its orientation signifies the direction of deformation.

By studying the principal deformation plot, engineers can gain insights into how the structure responds to loading conditions, where deformation concentrates, and how various components of the structure interact. This information is crucial for identifying potential failure modes, stress concentrations, and optimizing the design to ensure structural integrity and optimal performance (HAZIZI; GHALEEH; RASOOL, 2023). This refers to the primary or significant changes in shape or size that a structure undergoes as a result of applied loads in a finite element simulation. The principal deformations plot is presented in Figure 13.

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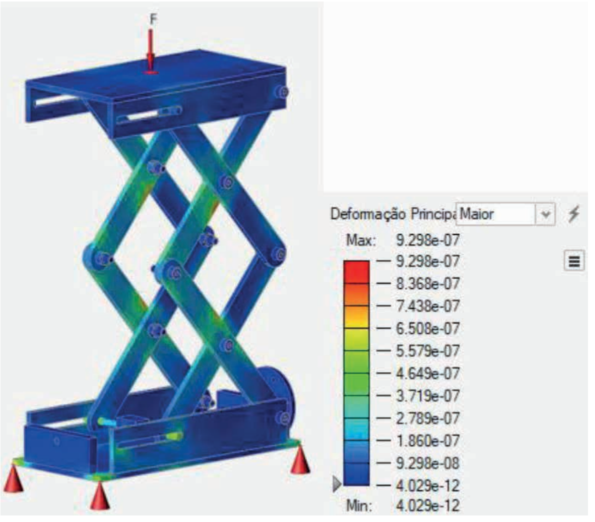

Figure 13 – Plot of main deformations of the lift platform

A plot of von Mises stresses is a graphical representation that illustrates the distribution of von Mises stress values within a structure under the influence of applied loads or constraints. Von Mises stress is a scalar value derived from the individual stress components (normal and shear stresses) at a given point, offering a simplified representation of stress state that helps assess the likelihood of material failure (AMSTUTZ; NOVOTNY, 2009).

Von Mises stress takes into account both the magnitudes of the individual stress components and their interactions, providing an indication of the effective stress level that a material experiences. This approach is particularly useful because it considers the combined effect of tension, compression, and shear stresses, providing a single stress value that can be compared to a material's yield strength to assess its potential for failure.

In a plot of von Mises stresses, different areas of a structure are color-coded or represented by contour lines to show the distribution of von Mises stress values. Colors or contour levels are used to highlight regions where stress concentrations are higher or lower, aiding engineers in identifying critical areas that might be prone to failure or require design adjustments (WANG *et al.*, 2013).

These plots are essential tools in FEA because they allow engineers to visualize stress distribution patterns and predict regions of potential material failure. By comparing von Mises stress values to a material's yield strength, engineers can determine if the structure will perform safely under the applied loads and make informed decisions about design modifications or material selection. The von Mises stresses plot is depicted in Figure 14.

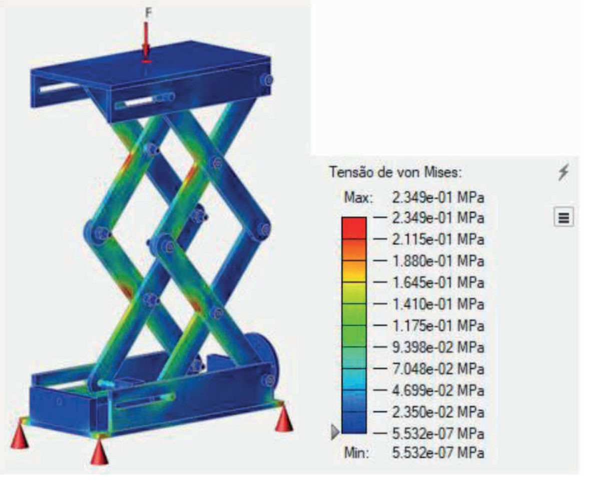

Figure 14 – Plot of von Mises stresses of the lift platform

A plot of safety factor provides a visual representation of the safety margins within a structure by illustrating the distribution of safety factor values across different regions. The safety factor is a numerical indicator that quantifies the ratio between the material's capacity to withstand applied loads and the actual loads experienced by the structure (FARIAS; NAYLOR, 1998).

The safety factor is calculated by dividing the material's ultimate strength (or yield strength) by the magnitude of the stresses exerted on the structure. A higher safety factor indicates a greater level of safety, as it signifies that the material's capacity to bear the loads is significantly higher than the applied loads (CASTALDO *et al.*, 2018).

In a plot of safety factor, the different sections of the structure are typically color-coded or represented with contour lines. The colors or contour levels illustrate the safety factor values at different locations within the structure. Areas with higher safety factors are usually depicted in one color range, while regions with lower safety factors are represented differently. This visualization helps engineers quickly identify regions that might have lower safety margins and could be at risk of potential failure (MACKAY; VAN KEULEN, 2013).

The plot of safety factor is an invaluable tool in FEA because it provides engineers with insights into the overall structural integrity. By observing areas with low safety factors, engineers can focus their attention on potential failure zones and make informed decisions to mitigate risks, whether by altering the design, modifying loading conditions, or adjusting material choices (UGAI, 1989). The safety factor plot of the lifting platform is presented in Figure 15.

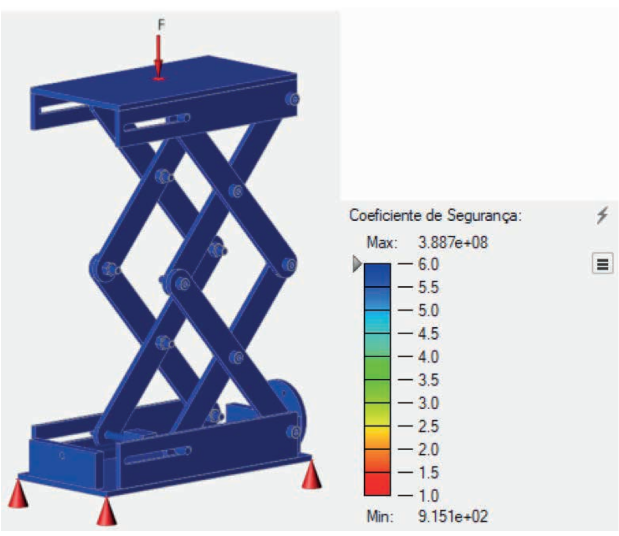

Figure 15 – Safety factor plot of the lift platform

Furthermore, an overarching trend is discernible, the model exhibits an elevated safety coefficient, effectively withstanding substantial stress levels. This is indicative of the inherent structural integrity and redundancy designed into the assembly.

Considering the well-established minimum approval criterion for steel, stipulated at 315 MPa, it can be conclusively affirmed that the structure unequivocally meets and surpasses this standard. Consequently, the prototype's structural design is validated, unequivocally propelling it towards the physical construction phase.

This discerning analysis not only corroborates the mechanical robustness of the platform but also substantiates the seamless integration of theoretical constructs, simulation methodologies, and empirical validation, a quintessential fusion underpinning modern engineering practice.

CONTROL SYSTEM

The control system governing the lift platform's operation was meticulously engineered utilizing the C++ programming language within the Arduino Integrated Development Environment (IDE). This system orchestrates the precise vertical motion of the platform through the judicious utilization of a stepper motor mechanism, synchronized with tactful push-button controls (PAN; ZHU, 2017). Rigorous software validation was conducted through meticulous simulation within the Proteus software suite. The individual software components, pivotal to this simulation endeavor, are meticulously delineated in the subsequent exposition (BADAMASI, 2014).

The operational framework of the control system is comprehensively encapsulated within the elucidated Figure 16.

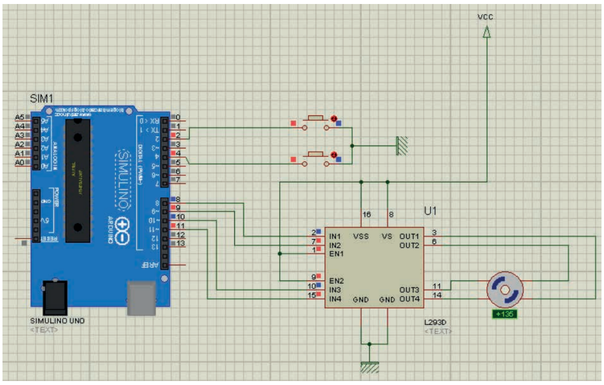

Figure 16 – Operational framework of the control system

The control system components are depicted from Figure 17 to Figure 20.

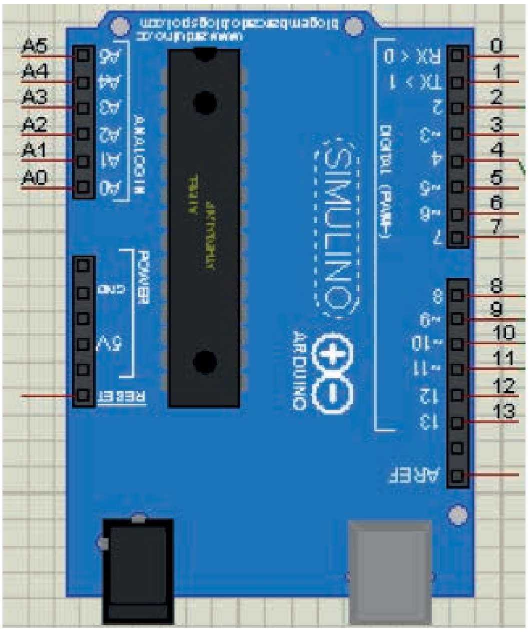

Figure 17 – Arduino used to perform platform control

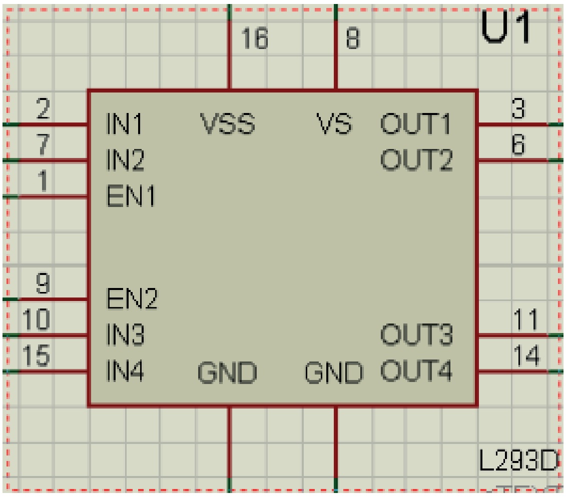

Figure 18 – Driver L293D

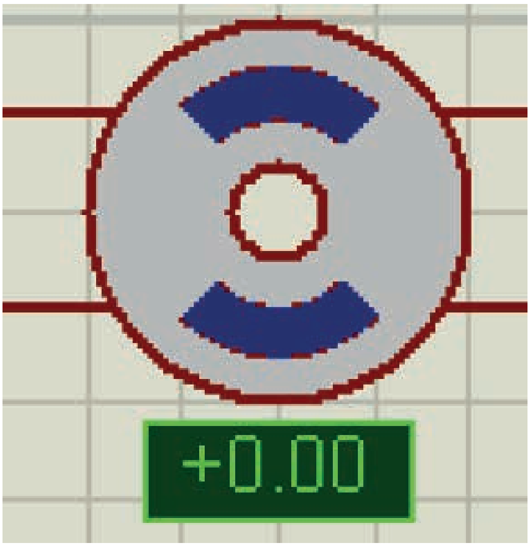

Figure 19 – Bis Stepper

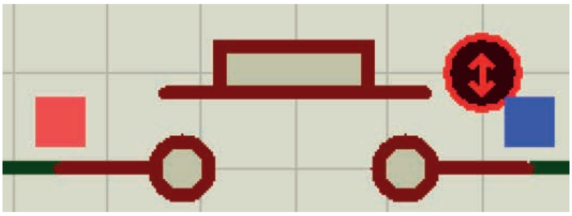

Figure 20 – Push Button

The executable source code, foundational to ensuring the coherent functionality of the control system, is meticulously documented in Appendix A. The core of this coding architecture capitalizes on the 'Stepper.h' library—a specialized utility instrumental in effectuating meticulous control over the

 DOI: https://doi.org/10.22533/at.ed.3174724260210

platform's motion through the employed stepper motor. This intricate orchestration empowers users to impart nuanced and secure commands for both upward and downward motions of the platform. Central to this is the meticulous specification of the precise number of steps undertaken by the motor during a complete rotational cycle (STEPS). Moreover, a Stepper Motor object ('Bis Stepper') is instantiated, meticulously configured to digital pins 8, 9, 10, and 11 on the Arduino platform—these pins, in a harmonious synergy, orchestrate the fine-grained control over the motor's dynamic behavior.

The push-button interfaces, thoughtfully integrated into the system's architecture, are meticulously configured as input entities, fortified with strategically activated pull-up resistors. The software's inherent logic, elegantly encapsulated within a systematic 'for' loop structure, intricately governs the platform's behavior through a pair of meticulously tailored conditional statements. This distinctive construct empowers users with a sophisticated control mechanism for both the ascension and descent of the platform. The initial conditional directive—facilitating the platform's downward motion—commences by ingeniously dictating the motor's clockwise rotation, concurrently advancing the step count. In harmonious tandem, the subsequent conditional directive orchestrates the platform's upward motion, orchestrating the motor's counterclockwise rotation with a concomitant incremental advancement of the step count.

A pivotal aspect of this construct involves the parameter 'i,' meticulously incremented with each iterative cycle of the 'for' loop. This orchestration meticulously induces a progressively augmented step count with each instance of button activation. The velocity dynamics of the motor are elegantly orchestrated through the 'Stepper. SetSpeed(50)' command, systematically establishing the rotational speed metric in rotations per minute (RPM).

However, the sophistication of this coding blueprint invites further optimization. Notably, the integration of end-of-travel sensors between the buttons and the Arduino emerges as an intriguing prospect (GALADIMA, 2014). This augmentation, inherently imbued with functional significance, envisages the judicious confinement of the platform's motion within a well-defined operational range. This envisioned augmentation presents a compelling avenue for elevating the system's robustness and operational finesse.

CONCLUSIONS

The integration of Problem-Based Learning with the design, simulation, prototyping, and automation of a small-scale scissor lift has presented an immersive journey into the heart of mechanical engineering education. This chapter synthesizes the transformative insights gained through this project and underscores its significance in shaping the engineers of tomorrow.

The scissor lift project exemplifies the symbiotic relationship between theoretical knowledge and hands-on experience. By engaging in a project that traverses the spectrum of mechanical engineering, students have been exposed to the multifaceted dimensions of their chosen field. The amalgamation of PBL principles with experiential learning has endowed them with not only technical prowess but also critical thinking, problem-solving acumen, and adaptability.

The iterative journey of the scissor lift project encapsulates the comprehensive nature of engineering design. From the inception of ideas and their refinement through iterative design processes, students have gained insights into the significance of meticulous decision-making. The simulation phase, driven by Finite Element Analysis, illuminated the importance of validating designs through virtual assessments. The transition from theoretical models to tangible prototypes underscored the value of practical considerations and hands-on craftsmanship.

The integration of automation, fueled by Arduino-based platforms, expanded students' horizons beyond traditional mechanical design. It introduced them to the realm of interdisciplinary applications, exposing them to the contemporary trend of automation and control systems in engineering.

The scissor lift project reflects the evolving landscape of engineering education. By offering students an opportunity to not only comprehend but also apply theoretical concepts in a real-world context, the project has nurtured a generation of engineers poised to innovate and adapt to industry demands. The project's synergy with the principles of Problem-Based Learning empowers students to engage with complex problems, cultivate teamwork, and communicate effectively—an invaluable skill set that extends beyond the classroom.

As this project concludes, it sets the stage for a future where the marriage of pedagogical innovation and hands-on exploration takes center stage. The scissor lift project serves as a blueprint, illustrating the immense potential of Problem-Based Learning in synergizing theoretical principles with practical expertise. This approach has not only enriched the learning experience of students but also illuminated the path forward for engineering education that is both responsive and transformative.

In essence, the scissor lift project is a testament to the power of experiential learning, interdisciplinary integration, and collaborative exploration. Through this endeavor, we stand on the precipice of a new era in engineering education—a realm where students not only inherit knowledge but also actively contribute to shaping the landscape of innovation.

ACKNOWLEDGEMENTS

The successful realization of this project would not have been possible without the unwavering support and resources provided by Centro Universitário FEI. We extend our sincere gratitude to the institution for fostering an environment of innovation and experiential learning, allowing us to embark on this transformative educational journey.

Additionally, we express our heartfelt appreciation to the dedicated personnel of the Centro de Laboratórios Mecânicos (CLM). Their expertise, guidance, and provision of state-of-the-art facilities played a crucial role in the design, simulation, prototyping, and automation phases of the scissor lift project. Their commitment to advancing engineering education has been instrumental in shaping the practical skills and perspectives of our students.

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APPENDIX A

```
#include <Stepper.h>
#define STEPS 5
Stepper stepper(STEPS, 8, 9, 10, 11);
const int botao2 = 2;
const int botao1 = 4;
void setup() {
pinMode(botao1, INPUT_PULLUP);
pinMode(botao2, INPUT_PULLUP);
}
void loop() {
for (int i = 0; i <= 2; i += 1) {
// botao descer
if (digitalRead(botao1) == 0) {
stepper.setSpeed(50);
stepper.step(i);
}
// botao subir
if (digitalRead(botao2) == 0) {
stepper.setSpeed(50);
stepper.step(-i);
}
}
}
```