FREE Desk, a reconfigurable and ergonomic smart desk

An EPS@ISEP 2021 Project

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This paper reports the research and development of a reconfigurable and ergonomic three-level desk, for people who live in small spaces. The main objective of the project was to design, simulate and test an ethically and sustainability-driven safe and transformable desk. The FREE desk proposal aims to create a comfortable and dynamic working environment for people while providing a transformable space for different daily activities. This goal was pursued by designing a reconfigurable product, a smart desk that offers the user three levels of adjustability: bench level, sitting desk level, and standing desk level. The desk includes a folding light-sensor lamp into the tabletop and an integrated battery, in order to create a proper working space. The selected materials have a low environmental impact. The solution comes with different options regarding the tabletop lifting mechanism. This paper describes the state of the art research, the ethics, sustainability, and marketing analyses, the design and simulation of the FREE desk as well as the obtained results.

CCS CONCEPTS • Education • Collaborative learning • Reconfigurable and ergonomic smart furniture

Additional Keywords and Phrases: European Project Semester, Working from home, Innovative solutions

1 Introduction

The European Project Semester (EPS) was created by Arvid Andersen in 1995 as a one-semester capstone program to train engineering undergraduates to behave and think internationally. To foster research, analytical, and organizational skills, it uses project-based learning and multicultural, multidisciplinary teamwork. Since 2011, EPS has been delivered by a network of 19 European universities, including the Instituto Superior de Engenharia do Porto, (ISEP) of the Polytechnic of Porto [1].

Since the pandemic global context changed our working behavior, a lot of studies show that this change impacted other aspects of our lives as well, such as the sleep quality, concentration capacity, stress level and imposed a more sedentary behavior [2]. There is a need to redefine our working from home model because this is something that will stay with us in the future.

In this project, the team designed a sit-to-stand desk that enables the user to define which position allows him/her to focus the best and be comfortable at the same time. The FREE product starts off as a bench, providing usability for other daily activities that may occur before or after working. It can be transformed into a sitting desk, and eventually into a standing desk. The objective is to provide a simple but functional and ergonomic design.

FREE is a product designed by a team of five students during the spring of 2021. The group is composed of people from various countries (Belgium, Romania, Macedonia and Poland), as well as different fields of study (computer science, product design, mechanical engineering, business and project management) from bachelor's and master's degrees. EPS provides the team with a learning environment to implement and improve the project-specific skills. Design, modeling, and testing of a practical, ethically, and sustainably aligned three-level flexible desk that is ergonomic and reconfigurable at the same time were among the open-ended project requirements. The cost of the materials and components required to build a prototype should not exceed 100 euros.

This paper focuses on a project that consists in creating an innovative, reconfigurable desk that transforms into a bench aimed for people who live in small spaces. Therefore, FREE stands for furniture, reconfigurable and ergonomic. The goal of the FREE product is to provide a dynamic and comfortable environment for working and an easily commuting approach to other daily activities. For providing ergonomics and reconfigurability at the same time, a system integrated into the product is conceived to facilitate the movability of the desk’s tabletop, transforming it into a bench, sitting desk, and standing desk. Furthermore, to enable productivity and comfort, the tabletop includes an integrated lamp and battery. The product also provides integrated ports, giving more autonomy to the user and a cleaner, uncluttered working environment.

This paper scaffolds the development of FREE three-level adjustable desk EPS project, starting by presenting the state-of-the-art research and background, explaining the design concepts, followed by the simulation, and predicted tests. Finally, the discussion and conclusions regarding the product FREE are pointed out.

2 Related Solutions

When considering the development of a reconfigurable and ergonomic furniture product, a clear overview of existing types of products that provide this functionality was performed. Transformable and ergonomic furniture examples were analyzed to create a broad perspective about the topic. The analysis was conducted considering the covid-19 pandemic’s global impact regarding the working habits and for that, the working-from-home model was explored in connection to our product.

Transformable furniture is designed based on the concept that the furniture’s design must involve at least two forms of appearance and function [3]. By having multiple functions, the furniture serves as an option for people who have little space. From a more general perspective, we analyzed some state-of-the-art existing transformable furniture designs, and then we focused mainly on adjustable desks.

As mentioned in the literature within the field [4], ergonomics is a scientific discipline that studies the relationships between humans and other system components. A good ergonomic design reduces incompatibilities between humans and their working space, resulting in the perfect working environment. Ergonomic furniture has the ability to adapt to the individual requirements of the user to ensure good posture. This type of furniture is specifically designed to ensure maximum comfort and overall wellness of the user. Ergonomic furniture is recommended in areas like the home office and offices where one tends to spend a lot of time sitting in one place [5, 6, 7].

Table 1 presents a few of the studied products that provide transformability and ergonomics.

Table 1: Studied products that provide transformability and ergonomics

Name	Features	Price (€)
Propr Office	electrical - adjustable height desk, electric lifters, durable and commercial quality laminate top (easy to clean and disinfect)	420-585
Jaswig StandUp Nomad	manually adjustable - tool-free assembly in under 15 min, easy to move around, ergonomic footrest, storage room, different height settings	250-420
Mateo Goods Sit-stand Desk	electrical - adjustable height desk, integrated wire management, 3 power modules with USB charging ports	1165
Bekant Desk	electrical - adjustable height desk, cable management net (keep desk tidy), deep table top, tabletop is wear-resistant, stain-resistant and easy to keep clean	449
Yaasa Desk	electrical - adjustable height desk, Hand switch beneath tabletop, lightweight	498
Vivo Desk	electrical - adjustable height desk, built in cable management, memory presets, timer to stand up	333
Allcam Desk	electrical - adjustable height desk, 2 button remote, assembly in 10 minutes	230
PrimeCables Desk	electrical - adjustable height desk, memory presets, adjustable width, can bear a high load (124kg), not very stable	270

The covid-19 pandemic situation changed the way of working all around the globe. Following sanitary restrictions, companies started to move towards remote work. Recent studies have shown that most of the workforce considers the future of work to be a hybrid model where some days employees work from the office and some days from home [8]. As another research shows, working from home can also affect people in a negative way, leading to lessening sleep quality and concentration, causing mood disturbances and stress and increasing sedentary behavior [9].

Given this change of working approach, new solutions are needed in order to accommodate a proper working environment in people's homes, one that is comfortable, dynamic, but can also be easily reconverted for other daily activities. Considering all the research done, and the present demands, a new solution for a reconfigurable desk was devised. This solution and the concepts embraced for its development are the core of the following sections.

3 Ethics

The team wanted the product to be compatible with the words "ethics" and "deontology," ensuring the product's true success. The view of the product and the purpose to which it aspires is influenced by the company's values, strategies, and actions, therefore operating and implementing human laws and standards is critical. As far as the engineering code of ethics, the team believes the project must adhere to those guidelines to create a professional and trustworthy brand for the product. The product's development and creation are in compliance with public safety, health, and welfare. Adopting a sustainable strategy and adhering to the laws of ethics is critical from the beginning of the design process until the product is distributed, in order to ensure the connection between the user and the product. In each phase of this

process, all variables, including engineering, marketing, sales, and the environment, must be considered. When it comes to the environmental aspect, the main goal is to create a sustainable and eco-friendly product as it can be, by reducing plastic and also material for packaging. The team concentrated on making the packaging material recyclable, which is also less harmful to the environment. The FREE desk is a product that addresses all of these concerns, providing excellent user convenience of use, adherence to all directives and legislation, and health and safety.

4 MARKETING

To fit the needs of a wider population and to create a better product for the masses and a good strategy in terms of sales, the team concentrated on analyzing the current market regarding desks and furniture in general. The FREE desk brand was defined based on the characteristics of the product, and strategic objectives such as developing a profitable business model and building a good relationship with the customers were pointed out to ensure a good follow-up. The logo shown in Figure 1 is designed to illustrate the name of the brand and its focus. During the demographic analysis, the primary target market was listed – the population working from home or from the company's office. Being transparent and sharing what we do, how we do it, and why is essential. The way FREE desk will establish its presence in the market is by using its website and social media channels (Facebook, LinkedIn, Instagram). By actively posting materials and using paid advertising, bigger audiences will be reached. The product will differentiate itself from the competition by using sustainable materials and innovative design, promoting an innovative concept - the three levels adjustable desk.

Figure 2: FREE desk logo.

5 SUSTAINABILITY

Sustainability means meeting our own needs without compromising the ability of future generations to meet their own [10]. The team is focusing on easy repair, disassembly, and recyclability to achieve this. The FREE desk will be made out of two materials: solid maple wood and aluminum. Reducing the amount of VOC's and keeping the materials recyclable were the driving factors behind the material choice. These materials also contribute to the durability of the desk, which distinguishes it from the fast furniture model. The team will be looking for wood with a certification from the FSC and/or the PEFC to make sure the wood is sustainably sourced. The user will have to assemble the boxes at home, this way the different wooden planks can be flat-packed. It makes it more efficient in terms of shipping. There is a LED light integrated into the desk, LEDs are known to be more efficient and last longer. The team will be using water-based finishes that contain

significantly fewer VOC's than conventional solvent-based finishes. This means less solvent that can evaporate into the home environment, which is beneficial for the environment as well as the user's health.

6 Proposed Solution

6.1 Concept

The FREE team developed a reconfigurable desk for people who live in a small space and need to reconfigure their furniture for multiple purposes. The desk is designed to offer the user three levels of adjustability: bench level, sitting desk level and standing desk level. For adjusting the tabletop, three types of mechanisms are available, making the desk's legs reconfigurable. The legs are integrated into two boxes, made from the same material as the tabletop. The purpose of the boxes is usability, providing storage space. Box 1 is designed like a cabinet with one door and box 2 is like a cabinet with three drawers. Both boxes are provided with ventilation. The tabletop is designed to create a dynamic and autonomous workplace that features an integrated battery and an auto sensor lamp. For providing ergonomics, the transformability functions of the tabletop as a sitting desk support an upright and straight posture of the users. Another key concept of our product is the "assemble it yourself" method. The FREE desk is sent partially assembled, with instructions that will help the user set it up properly. This assembly concept ensures easy and compact transport.

Figure 2: The concept model of the FREE desk - a scale cardboard model prototype.

6.2 Specifications

In order to pursue the project objective of providing a proper working environment, the team estimated a working space (the tabletop) of at least 0.70 m2 to suit one person. According to this, the following dimensions were defined. The transformable mechanism has a minimum height of 53 cm for the electrical mechanism, 58 cm respectively for the crank lifting mechanism (for the bench level) and a maximum height of 120 cm for the electrical mechanism, 110 cm respectively for the crank lifting mechanism (for the standing desk level). In between (for the sitting desk level) the height is adjustable and can be decided by the user. The mechanism is manufactured from aluminum, having a total weight of 18 kg, together with the desk's legs. Both boxes and the tabletop are manufactured from solid maple wood. The two boxes have the same dimensions, with a height of 50 cm, length of 60 cm and width of 30 cm. Box 1 has a door with 2 aluminum

hinges, and box 2 has 3 drawers held by 6 aluminum drawer slides. Box 1 has a total weight of 10 kg. Box 2 is heavier, with a total weight of 11 kg. The tabletop dimensions are: 60 x 120 cm, and it can stand a maximum load of 90 kg. The battery is integrated on the bottom side. The lamp is integrated into the tabletop and can slide in and out with ease.

Figure 3: The FREE desk's boxes design seen from multiple angles.

6.3 Design

6.3.1 Structure

The structure of the FREE desk consists of the desk's legs, involving the lifting mechanism, the 2 boxes, and the tabletop. The desk can be configured in three positions as a bench, a sitting desk, and a standing desk. When having the desk in a bench position, a compact version of the product is created. In this position, the desk maintains all the other features, the storage space provided by the boxes, and the integrated battery. The lamp integrated into the tabletop can slide inside, facilitating a flat surface that serves as a seat. When activating the lifting mechanism, the bench can transform into a sitting desk or standing desk. In the next section, a deeper understanding of the lifting mechanism is presented. In Figure 4 the 3 levels of adjustability are presented together with the structure of the boxes and the tabletop. In Figure 5 a closeup of the integrated lamp is presented.

Figure 4: The FREE desk - the 3 levels of adjustability using a crank lifting mechanism.

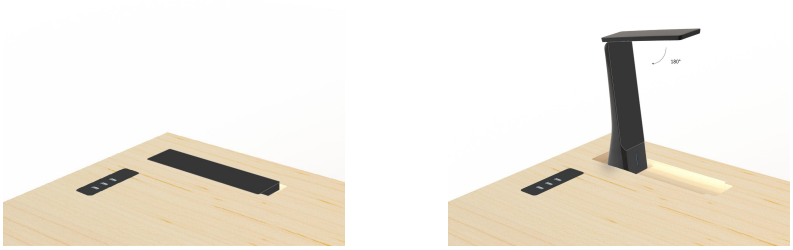


Figure 5: The FREE desk - a closeup of the integrated lamp.

*6.3.2 **Transformable mechanism***

The team analyzed multiple mechanism options, and in the end decided to provide 3 lifting mechanisms for the product, based on the user's needs and budget.

Electrical Mechanism

The mechanism consists of one motor to lift the two legs of the desk, ranging from 50 to 120 cm. It is quiet (under 50 dB) when lifting and lowering the desk, working with a source of power of 220 V. The team's main choice for the product is this system as it is easy and comfortable to use, dynamic, making the desk easy to reconfigure in the three positions, concomitantly with a strong structure.

Crank Lifting Mechanism

The crank is located in a corner under the tabletop and moves at a rate of 30 mm per turn of a handle, adjusting from bench to sitting in 6-7 turns, and from sitting to standing in 12 turns, in total requiring 19 handle turns to get from the bench position to the standing desk. The team explored this mechanism in order to offer a cheaper alternative for the electrical mechanism but maintaining the dynamics and ease of use. The challenge encountered was regarding the maximum capacity of the mechanism to extend, limiting the height that the tabletop could reach. The mechanism's limitations make it hard to adjust the desk at the proper three heights for the three positions, and in this case, for the bench level, the height is 58 cm and for the standing desk, the tabletop can reach a maximum of 110 cm.

Sliding Mechanism with Lock Pin

The mechanism uses spring button clips to adjust height settings. The team analyzed the easiest system that can provide height reconfigurability at the lowest price. The advantage is that the product can be configured in the three positions at a low cost of production. The main disadvantage is regarding usability, the process of reconfiguration is uncomfortable for the user.

Pneumatic System Mechanism

Pneumatic lifts employ a lifting mechanism that incorporates a hollow cylinder and piston. An external motor or pump moves the piston within the cylinder, increasing the internal air pressure and causing the cylinder to move along the axis of the piston. This mechanism does not require electricity and can lift even very heavy loads with very little force applied. It is also quite inexpensive compared to electric mechanisms and provides easy usage, but pricier compared to crank lifting mechanisms. The team analyzed this option, but because the mechanism has limited height adjustability, it can't provide all the desired features.

Scissor Mechanism

In this type of mechanism, extension is achieved by applying pressure to the outside of a set of supports located at one end of the mechanism, elongating the crossing pattern. The team analyzed this mechanism because it can provide a relatively cheap, reliable, and not so complex solution ensuring smooth vertical movement. Some big disadvantages are that the mechanism is quite heavy, and it is not very eye-pleasing, and for these reasons, the mechanism is not an option for the final product.

*6.3.3 **Autonomous integrations***

Battery

The team researched for batteries available on the market that can provide autonomy of work. This feature is ideal for locations where there are no wall plugs available close by. The integrated battery works like a power tank, providing power for the lamp and also multiple ports for different devices. A battery with large capacity may provide up to 4 weeks of power on a single charge. Also, the recharging is easy, via a standard USB overnight. As the integrated lamp works with a LED light, it is safe with a 12V supply. A transformer is used, in order to convert voltages from higher to lower values.

Sensor Lamp

The team utilized a sensor called LDR (light dependent resistor) to detect the intensity of light or darkness. When there is a high intensity of light, the LDR permits greater voltages to flow through it (low resistance), and when there is no light, it passes a low voltage (high resistance). The LDR gives out an analog voltage when connected to VCC (5V), which varies in magnitude in direct proportion to the input light intensity on it. Because the LDR produces an analog voltage, it is linked to an Arduino's analog input pin. The Arduino then translates the analog voltage (from 0 to 5V) into a digital value in the range of 0 to 255 using its built-in ADC (analog-to-digital converter) (0-1023). The translated digital values read from the LDR through the Arduino will be in the range of 800-1023, if there is enough light in its surroundings or on its surface. Furthermore, the team programmed the Arduino to activate a relay. It turns on an appliance (light bulb) when the light intensity is low, that is, when the digital values read are greater than normal.

*6.3.4 **Packaging***

An eco-friendly way of packaging was pursued by using sustainable packaging solutions. There are some criteria that a package must meet in order to be sustainable. It has to be cost-effective, support ecological health, be ethically correct and it has to have a wider range of usage, such as reusing the box. The team considered the send-box-back solution, where customers can fill the box with used electronic devices, batteries, and send the box back. From there, the company will navigate the package to appropriate services. Also, the empty space inside the transportation box will be limited by properly placing the components on top of each other, adjusting the sizes of parts to the packing order. The small pieces of cardboard will be used to compartmentalize the inside of drawers and boxes. One main objective of this product is to provide proper storage space, so the team included a DIY for the user in order to reuse the cardboard. Another aspect that makes the packaging sustainable is the limited use of plastic bags and foils. The plastic protective foil is replaced with a bubble wrap made of granulate, which is 100% recyclable and biodegradable. Also, plastic string pouches for mini tool kits and screws are replaced with compostable ones made from a combination of bio-based and synthetic polymer materials.

6.4 **Proof-of-Concept Development**

The team decided to make a proof-of-concept model to get a better view of how the desk will look and make sure all the parts were defined. One of the project’s requirements was building a prototype of the product,

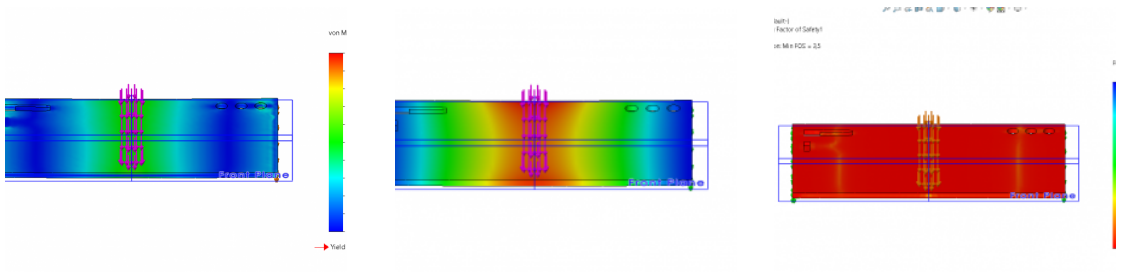
considering not exceeding the budget of 100 euros for the construction. Unfortunately, the team couldn't use the same materials as for the proposed solution but concentrated on reusing old material and integrating it properly, making the prototype as eco-friendly as possible. The materials which were used were: an old desk for the structure and the tabletop, PVC material for the boxes, a LED lamp, and an external battery. An Arduino circuit was built in order to represent the sensor-lamp concept. The scope was to analyze the comfort of the desk and its ergonomic properties by transforming it. The boxes were built in order to show usability when it comes to storage and illustrating the idea of a desk as a home working environment.

Figure 5: The FREE desk built prototype.

7 Simulation Tests & Results

Using simulation software, the team assured that the FREE desk is strong enough to withstand the possible loads it will have to endure, both in the bench and desk position. The lifting mechanisms can carry certain loads. These are tested professionally by the companies who produce them. The team did an additional test on the tabletop to make sure it could withstand the pressure of the user sitting on it. The team set the weight of one person at 90 kilograms and used a safety factor of 2, which results in a load of 180 kg (which is approximately 1800N). By using this safety factor, we can be sure that our desk can withstand this load even if the user is standing on it. We have put the load in the middle of the table, the most vulnerable part. By conducting the simulation for the first time, the team could see the maximum displacement, while using

double the weight of the user, is 2.3 mm. This is acceptable, given that the test considered a 'worst-case scenario'. What's really important is the factor of safety. This should minimally be 2, and from the test, it resulted as 4. This means that the desk can withstand this pressure and it can even have a lighter tabletop. The tests considered a tabletop thickness of 3 mm. The team decided to eliminate 5 mm of the tabletop, resulting in a thickness of 2.5 mm. This results in a factor of safety of 3.5, which is the proper value. The maximum displacement now has a value of 3.4 mm. These final results are illustrated in Figure 6.



Stress Displacement Factor of Safety

Figure 4: Results of the simulation test

8 Discussions

8.1 Lifting Mechanism

The team considered integrating three mechanisms as options for the product: the electrical mechanism, the crank lifting mechanism, and the sliding mechanism with lock-pin. The FREE Desk is presented as a product with a range of mechanisms from which the user can choose, based on budget and ease of use. The premium version of the product is the electrical one, considered the most premium model, the one that provides all the functionalities and the easiest usability. The crank lifting mechanism comes with its limitations, making the bench level to be higher compared with the proposed model, and also the standing desk lower compared with the proposed model. The team conducted the test and discovered that it is impossible for the mechanism to have an adjustment of more than 52 cm. In this case, the bench level should be at 58 cm instead of 53 cm, and 110 cm instead of 120 cm respectively for the standing position. The sliding mechanism with lock-pin is the cheapest one, providing all the functionalities, but it comes with the inconvenience of use when wanting to adjust the tabletop level.

8.2 Prototype

The team created a scale model to get a better vision of how the FREE desk would look and work but because it could not use the real materials, no tests were able to simulate the model. This limited the team to check the functionality of the originally proposed desk. Not being able to test the proposed lifting mechanisms is the first limitation. In this context, the team was able to only test the advantages of the transformability concept and the limited ergonomics characteristics provided by two levels of adjustability included in the prototype. As a proof-of-concept, the transformability proved to offer some ergonomy for the user by providing the possibility to adjust the tabletop height. As shown in the state-of-the-art chapter, numerous studies already proved the benefits of adjustable desks. In order to test the mechanisms, more work is needed. Not being able to test the bench model is the second limitation. The prototype focuses on the sitting and standing desk positions, but the bench model is neglected. When looking at the proof-of-concept model, a conclusion can be

made that everything will fit 'normally' but this cannot be ensured as the model wasn't made considering the original concept. The two boxes were represented in the prototype but only to show their usability as storage space, not also as part of the bench position. Considering the storage purpose, the boxes proved to serve their role, making the overall working environment look more like a complete space for productive work. The team focused on the implementation of the sensor-lamp concept, integrating the LED lamp and the battery in the prototype. As expected, these features proved to be important features in order to create an autonomous and dynamic working environment. In the near future, a prototype based on the original model has to be made to check all the above-presented limitations.

9 Conclusions

9.1 Project Outcomes

The team set out to test the feasibility of creating a successful business surrounding the idea of providing an ergonomic adjustable desk for people who live in small spaces. The team created a marketing plan to promote the product and target people and organizations. A detailed business plan was created to specify logistics, costs, supplies, and the target consumers. In addition to the marketing plan, there were also goals of sustainability and ethical concerns pursued. In terms of creating the desk, the team has made a start in testing the concept by building the prototype. As further steps, the team will continue developing the desk while striving for an optimal prototype, with the original materials, to test the product. The team would like to investigate potential problems in order to prevent risks in the future and develop countermeasures for prevention.

9.2 Personal Outcomes

Regarding this one-semester learning experience, the team members shared the following opinions:

"When I have entered the EPS@ISEP programme, I knew that it is, above all, an opportunity to get out of my comfort zone, to work with a team in a foreign language while combining our different fields of study and to live and travel in a beautiful city and country. At the beginning, the COVID-19 situation here made things go slower in an online environment, and also not all the team members were in the city at that time. Things started to get better from April and the team had weekly meetings at the university to discuss the development of the project. I have realized that it does not always matter if you do not have the knowledge or if you feel insecure, if you are not well prepared or if you do not know what you can bring to the table. This experience teaches you on-the-go and brings out what is best in you. You only have to bring the willingness and motivation to develop on a personal and professional level. Here I have discovered what my capabilities are and how I can adjust to a team that I have never met before." - Gabriel

"I think our team can agree that this EPS experience was very useful, both on a personal and professional level. During the course of this semester, we learned to work with each member's strengths and weaknesses and gained knowledge in a field that we weren't really familiar with. Working together in an international team is a challenge, given the cultural and educational differences. The team learned to deal with these challenges, even in the midst of this pandemic. The experience of exploring Portugal and meeting new people was an incredible plus, and makes this experience an unforgettable one." - Anastasia

"The European Project semester was totally different from my usual projects. Working together with a team to solve a problem is one of my favorite activities. It was an amazing opportunity to work together with students from different study backgrounds and different nationalities. I am happy that I had this opportunity and I thank my colleagues and the teachers for all the lessons taught." - Silvia

"It was a very hard and challenging experience for me as I wasn't able to join my teammates in Porto. Instead I was working from my hometown in Łódź, Poland. Even though we didn't meet in person I feel

like I’ve met a very valuable, hardworking and helpful group of people. Sometimes remote work created some miscommunications but with the help of those guys they brought me to the right track and I’ve done everything I could to contribute to the project. I hope the pandemic will be forgotten in a short time and I’ll have an opportunity to visit Porto and make up for the lost time.” - Marcel

“Working with individuals of various countries and backgrounds at EPS was a fantastic experience for me. I learnt a lot about cooperation, work consistency, and product development, and my present field of expertise has considerably increased. To add to that, I feel that EPS not only aided me in expanding my academic and practical skills, but also introduced me to new people.” - Nicola

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