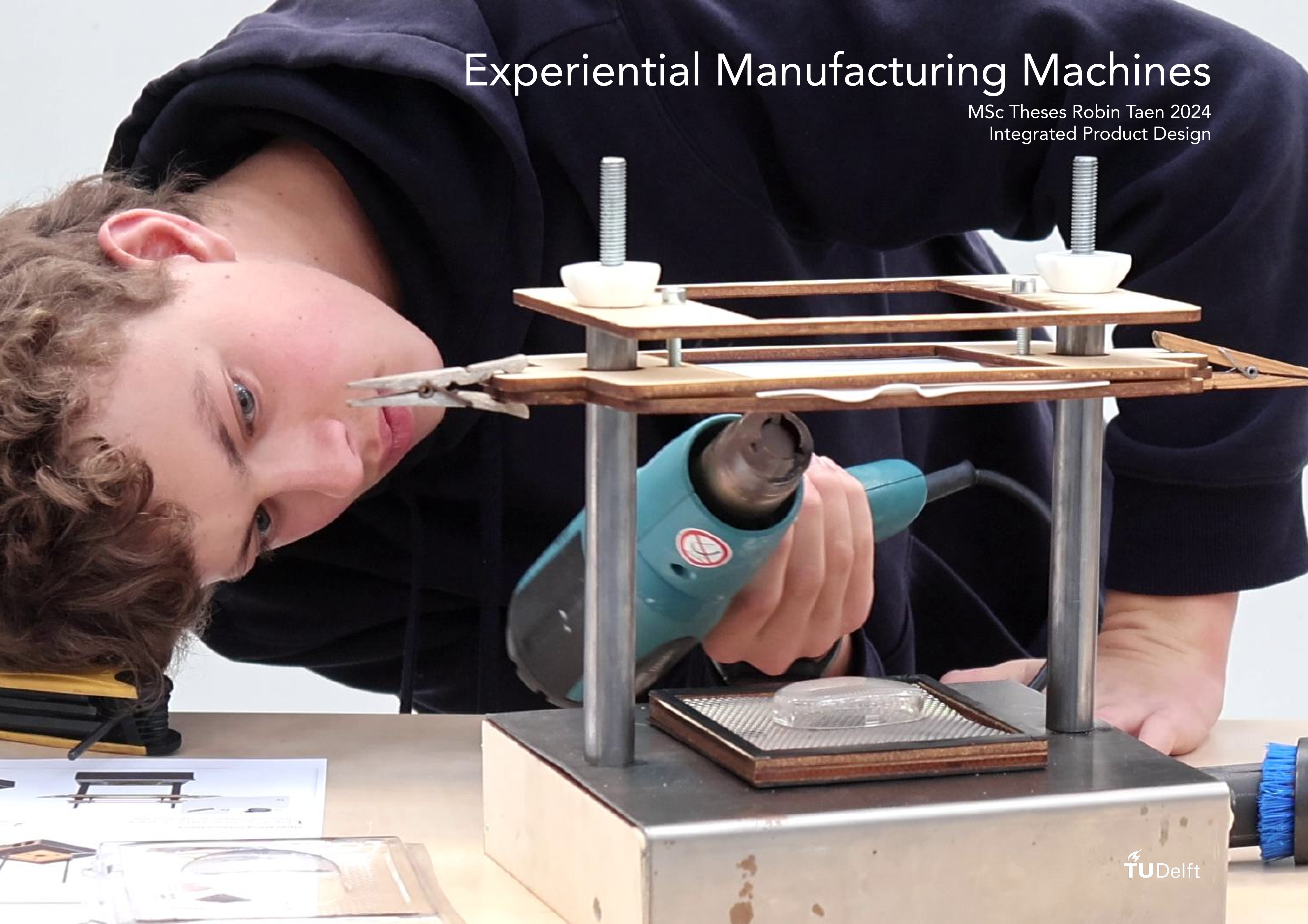
Experiential Manufacturing Machines

MSc Theses Robin Taen 2024
Integrated Product Design



Acknowledgments

I would like to open this thesis by expressing my gratitude to everyone who supported me throughout this project.

First, I would like to thank my supervisory team: Dr. ir. S.F.J. (Bas) Flipsen, the Chair and client of the project. His excitement and critical view gave me the necessary support in making it more scientific and argument-based. My mentor, Ir. T.J. (Tobias) Hebbink, who gave me the freedom and structure during the project, which led me to follow and discover my own project structure based on agile design and fast physical prototype iterations.

Second, I would like to thank Kiet Stiemer, who accompanied me at the beginning of the project. Kiet, who also worked on a thesis related to this topic, partnered with me in developing the online questionnaire and contributed to the initial analysis. Although our design assignments shifted later in the project, he was always available for a good chat and constructive feedback.

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I would like to thank all the participants and interviewees who volunteered their time and shared valuable insights for this research.

I am grateful to my family and friends for their support throughout the writing process.

Lastly, special thanks to the PMB for providing access to their facilities and assisting me with all my questions, which was essential for creating the various prototypes.

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Abstract

With the introduction of the new Industrial Design Engineering (IDE) bachelor in 2021 all courses underwent a revision to promote, amongst other, an autonomous learning attitude. The conventional approach of teaching engineering relied on direct instructions and problem-based learning and proved to be inadequate. With a short retention time and limited deeper concept understanding, students struggled to apply their engineering knowledge in capstone design projects. This project aims to develop new educational materials to align better with this new attitude.

The project is approached with a hands-on and iterative mindset. More than nine prototypes have been developed and tested with users. The result is a versatile educational toolkit that can be configured into small-scale manufacturing machines. Currently three configurations are developed, but due to its modular components more configurations can be added in the future. These machines provide students with hands-on experience related to manufacturing techniques and its opportunities, limitations, and materials. By being intriguing, exciting, versatile, and user-friendly, the machines stimulate active involvement. With a focus on producibility and cost-effectiveness, this toolkit is designed to integrate seamlessly into the IDE bachelor's program, offering an accessible, practical, and engaging learning resource that supports deeper concept understanding.

Problem statement*

With the introduction of the new IDE bachelor in 2021 all courses underwent a revision to promote, amongst other, an autonomous learning attitude. The conventional approach of teaching engineering relied on direct instructions and problem-based learning and proved to be inadequate. With a short retention time and limited deeper concept understanding, students struggled to apply their engineering knowledge in capstone design projects. (Flipsen et al., 2023)

Assignment

Provide students with an experiential setup that can serve as a standalone educational tool or as part of a productive failure workshop to learn about manufacturing and its materials, as well as its design requirements, limitations and opportunities. With the goal to improve deeper conceptual understanding and enhance knowledge retention.

Vision

An educational tool/setup is envisioned that actively engages students by being **intriguing, exciting, versatile, and user-friendly**. By utilizing a productive failure and experiential learning approach, this setup will enable students to gain a deeper understanding and overall intuitive feel. For easy implementation the envisioned setup is cost-effective and easy to maintain.

*Due to this agile approach this report is not all in chronological order. During the process the objectives changed and got tweaked since new information was revealed, assumptions were checked and the scope size changed. To find how this changed during the process please be referred to appendix A.1. and A.1.1 for the original design brief.

Method and reading guide

During this project, I employed an Agile design approach. Agile design is an iterative process that differs from the conventional waterfall model, where each design phase is completed sequentially. Instead, Agile design involves cycling through all phases multiple times in shorter time spans, allowing for continuous refinement and improvement throughout the process (Van Boeijen et al., 2014). Not only the design phases, but all steps are revisited several times throughout development to enhance the product characteristics based on input from end users. This approach ensures that the final product will more effectively address real-world needs (Pata et al., 2021).

This leads to a less chronological and easy-to-read report structure. To create an overview, I structured this report into an initial analysis phase and three prototype phases, numbered as versions. Each phase is recognizable by its colour. Within each phase, value characteristics, insights, and requirements are labelled in different shades of grey. The meanings of these labels are explained below. The report concludes with a final justification with all the insights that are gathered throughout the process and follow-up steps to make this design a success.

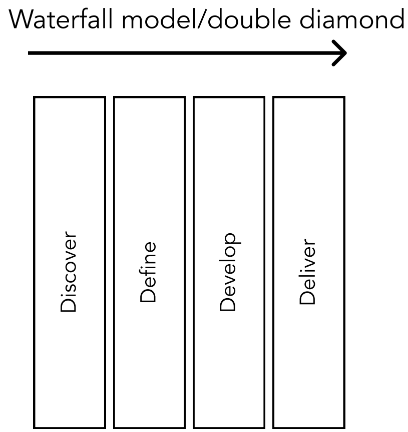
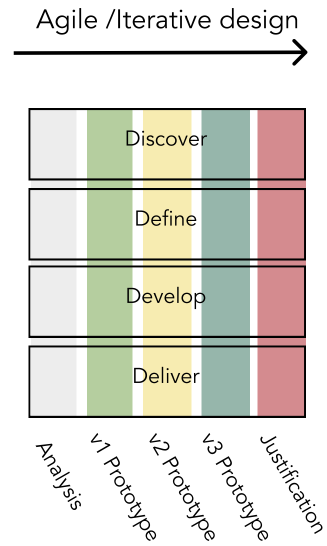


Illustration by me, inspired by Kiss (2023).



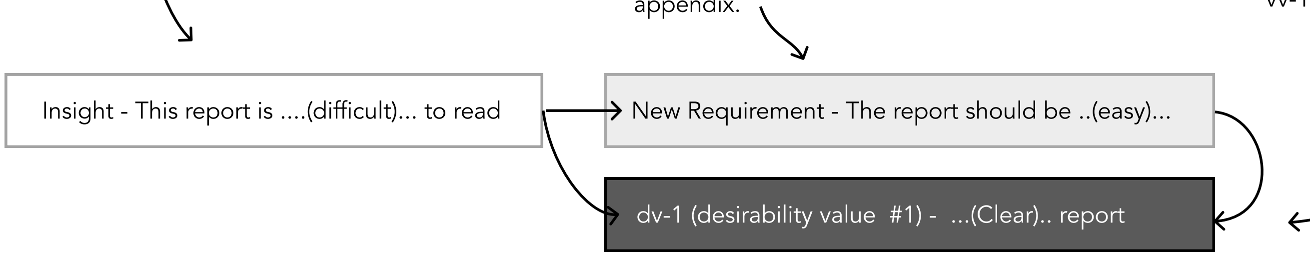
These labels (white body with the referring phase colour as stroke and black text) show either an <u>insight, validation</u> or <u>general goal</u> from the research of that chapter. If applicable, these will form a requirement and/or value characteristics.

These labels (light grey body with black text) are either a <u>requirement</u> or <u>wish</u> derived from the research and insights. If it is labelled as 'New', it indicates that this requirement is being introduced for the first time in the report. If it is labelled as 'Established (Est.)', it means the requirement has been previously mentioned, but the current insight provides additional justification for its inclusion. All requirements of each phase are listed in the appendix.

These labels (dark grey body with white text) are used in the end of the report to validate the design on three <u>value characteristics</u>;

- Desirability, Do we need or want it?
- Feasibility, Can we achieve it?
- Viability, Can it be sustained over time?

dv-1 stands for; 'desirability value #1'
fv-1 stands for; 'feasibility value #1'
vv-1 stands for; 'viability value #1'



Glossary

AP = Advanced Prototyping—minor course.

DI = Direct Instruction—educational approach.

EL = Experiential Learning—educational approach.

IDE =Faculty of Industrial Design Engineering at TU Delft.

Injection Moulding = Manufacturing process.

Iterations = Design iterations involve refining a product through repeated cycles of prototyping, testing, feedback, and adjustments.

LETT = Low-end Tensile Tester—an experiential setup developed at TU Delft and currently in use.

LO = Learning Objectives—created by the course coordinators.

Low-Fi = Low-fidelity materials that are cheap, basic materials for prototypes.

M&M =Materials and Manufacturing—elective course.

Metal Bending = Manufacturing process.

NVM lines =A Dutch abbreviation for the subject about internal stress, covering Normal Force (N), Shear Force (V), and Bending Moment (M) diagrams.

OER = Final Attainment Levels—developed by the faculty.

PF = Productive Failure—educational approach.

PMB = Model-making workshop at the Faculty of Industrial Design Engineering (IDE).

UPE = Understanding Product Engineering—first-year bachelor's course.

Vacuum Forming = Manufacturing process.

Contents

Research conducted with end-users, such as a questionnaire or a user test is outlined in black.

Analysis
What is the problem and its context?

1. Scope

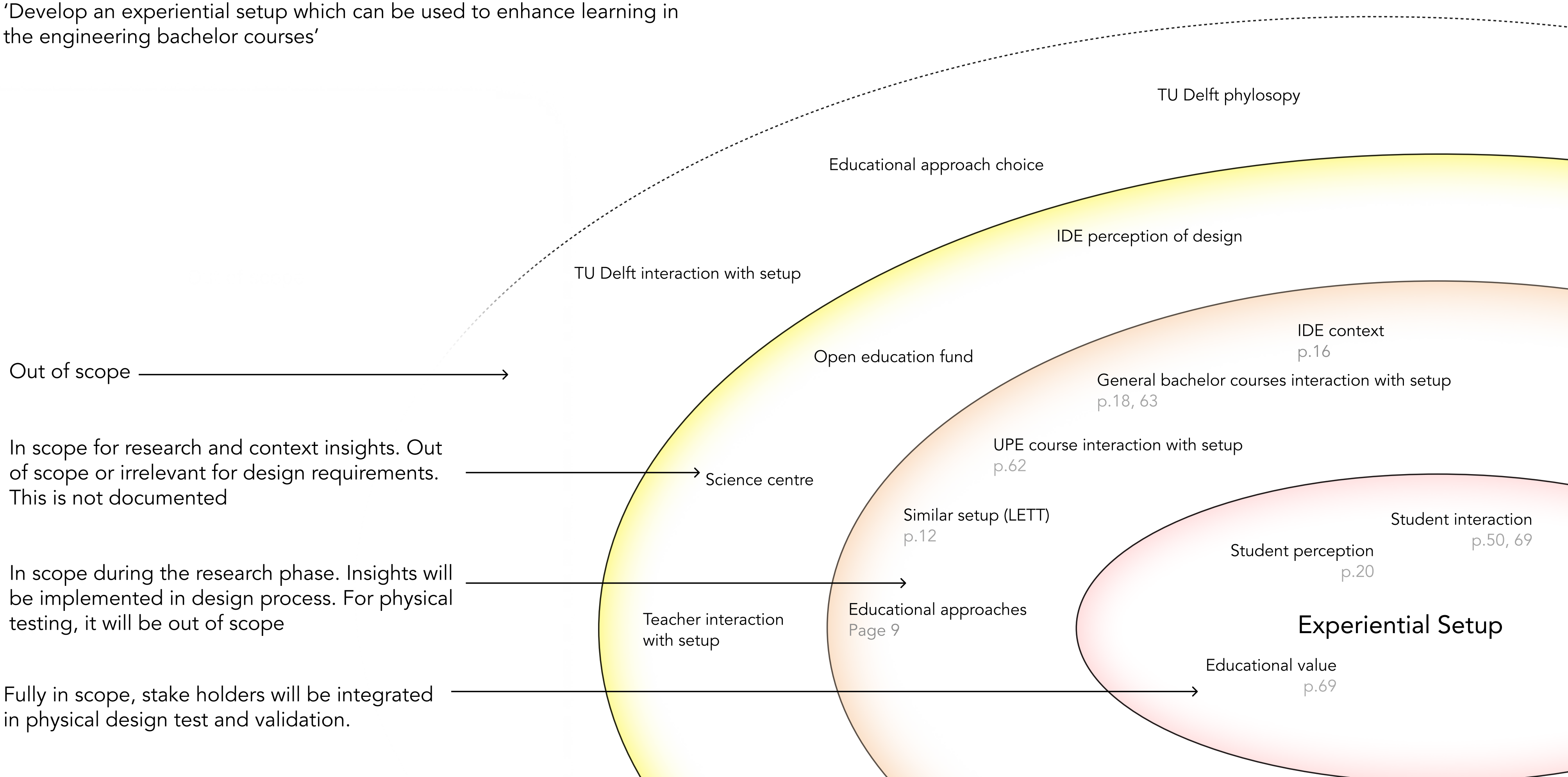
'Provide students with an experiential setup that can serve as a standalone educational tool or as part of a productive failure workshop to learn about manufacturing and its materials, as well as its design requirements, limitations and opportunities. With the goal to improve deeper conceptual understanding and enhance knowledge retention.'

This is the assignment description at the start of this report; however, this is not the assignment that this project started with. Over time, the assignment was refined and tweaked. In this report, this process will be shown. It started with:

'Develop an experiential setup which can be used to enhance learning in the engineering bachelor courses'

This is a broad assignment that can be approached from various perspectives and stakeholders. Therefore, this scope is created to clearly define what will be researched and developed, along with its importance. Each ring in the diagram represents the level of influence on the project and indicates where relevant information about this subject can be found.

In the next chapters we will dive deeper into this statement and explain and research different aspects of the statement.



2. Educational approaches

To 'Develop an experiential setup which can be used to enhance learning in the engineering bachelor courses', it is essential to understand what experiential learning/setup means and why it is chosen as the design goal for this project.

Experiential Learning (EL) is an educational approach based on the concept that students learn best when they are actively engaged with the material by experiencing and reflecting on what they've learned in real-world situations. This hands-on approach helps deepen understanding and makes learning more meaningful and memorable (Gadola & Chindamo, 2017).

For example; A student builds a small-scale bridge, tests its load-bearing capacity, reflects on the structural integrity and design, and uses this knowledge to improve future engineering projects.

Not to be confused with Experimental Learning where a student conducts a chemistry experiment in a lab, follows specific procedures, collects data, and analyses the results to understand chemical reactions.

In summary, experiential learning involves learning through practical application and reflection on real-world experiences, while experimental learning is centred around scientific experimentation and data analysis within a controlled environment.

Experiential Learning (EL)

- **Active engagement**
  Students participate actively, learning through hands-on experience.
- **Reflection**
  A crucial component where students reflect on their experiences to derive meaning and improve future performance.
- **Application**
  Experiential learning emphasizes applying new found knowledge and skills to real-world contexts, reinforcing learning through practical application.

J.W. Gentry (1990) states that feedback is critical for proper learning to take place after an experience. The student should not be allowed to conclude what was learned without receiving feedback; there is too much evidence that human beings do not do this properly. The debriefing session is crucial. Students need to articulate their perception of what was learned, and the instructor needs to put things into a broader perspective. If the students correctly uncover what the key variables are in the present exercise, discussion should probe whether those variables are also dominant in other situations.

> *" I HEAR AND I FORGET*
> *I SEE AND I REMEMBER*
> *I DO AND I UNDERSTAND. "*
>
> Confusius or Xunzi

Why this approach is used in this project is a bit more nuanced. The project brief (see Appendix A.1) describes that this approach can enhance learning in the engineering bachelor courses This is a bold statement to take for granted, and will therefore be tested. It is beyond the research scope of this project to extensively argue why experiential learning is chosen over other conventional approaches. For now, this statement is accepted based on scientific research (Kapur, 2019; Morris, 2019) and the support of IDE staff.

It is also important to know that one of the engineering bachelor courses, Understanding Product Engineering, follows a productive failure educational approach.

Productive failure (PF)

Productive failure is a educational approach that is used in the engineering bachelor course, Understanding Product Engineering (UPE). The goal is to design for the engineering bachelor courses. To get a deeper understanding of the design context and where the setup will be implemented is it essential to know how and if an experiential approach can blend in with the existing (PF) approach that is used.

Both PF and EL (experiential learning) are educational approaches that align with the principles of constructivism. Constructivism states that learners build understanding and knowledge by actively engaging in experiences and reflecting on those experiences. (Tobias & Duffy, 2009).

Productive failure flips the traditional learning process and starts with an explorative problem which students are unable to solve. This leads to struggle and awareness of their knowledge gaps. After this phase, instruction is provided to explain the missing concepts. This approach engages students in active problem-solving, aiming to enhance the retention of theoretical concepts (Flipsen et al., 2023).

Kapur (2019) explains that both direct instruction (such as lectures and books) and productive failure are effective for learning basic knowledge. However, when you ask students about deeper conceptual understanding, that is when productive failure outperforms direct instruction. Conceptual understanding goes beyond memorizing facts or procedures and involves grasping the underlying concepts that explain why things work or how they are related.

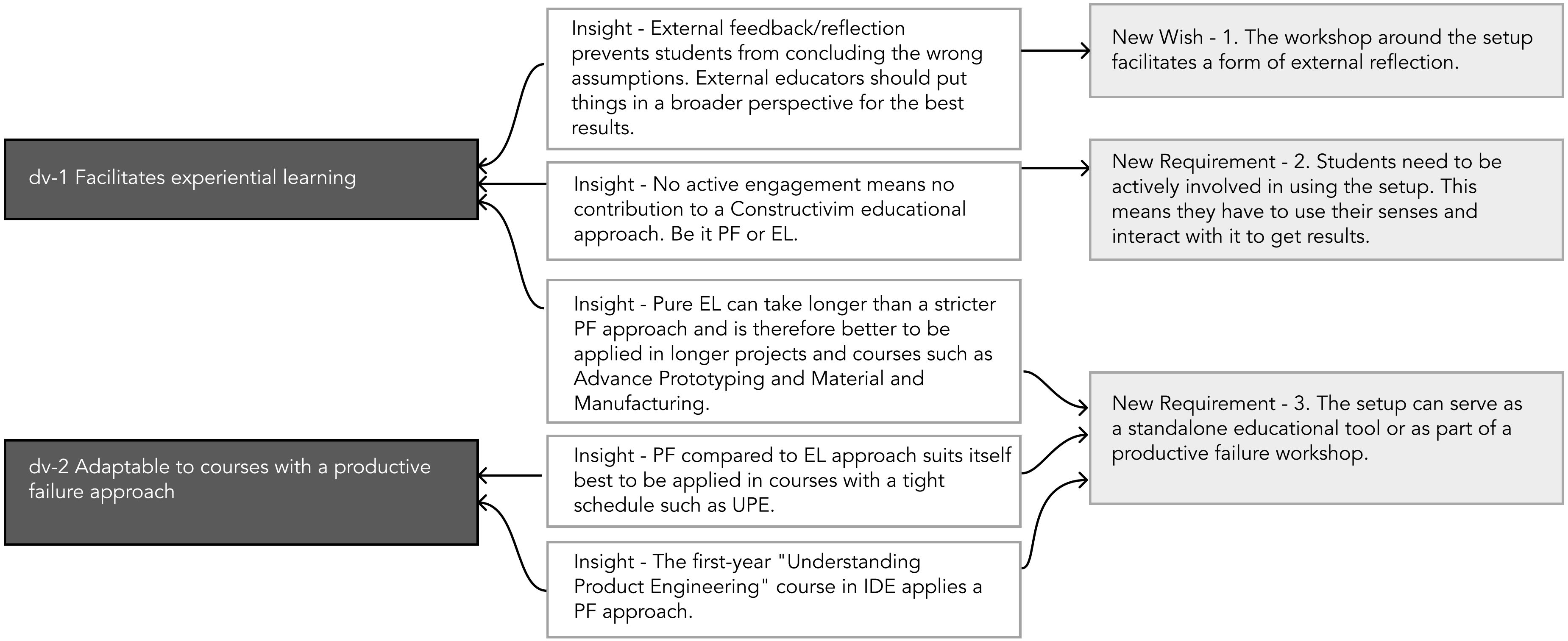
An interesting insight is that the productive failure approach is effective in scenarios where engineering principles need to be understood within a specific time frame. The problems become evident early on because the assignments are intentionally designed for students to fail, helping them quickly develop a deeper understanding of the subject matter. Experiential learning is more easily applied in ongoing projects and courses where students continuously engage in practical work and reflect on their experiences to improve and learn.

Productive Failure (PF)

- **Active engagement**
  Students participate actively, trying out solutions and learning from their mistakes.
- **Initial Struggle**
  Students are intentionally presented with challenging problems without prior instruction. Leading to initial failure. Failure activates prior knowledge, increases awareness of limits, and motivates learners to bridge knowledge gaps, facilitating deep learning.
- **Delayed Instruction**
  After the initial struggle, teachers provide structured instruction, helping students make sense/reflecting of their experiences, correct misconceptions, and deepen their understanding of the concepts.

Educational approaches insights and requirements.

From the chapter above, ´Educational approaches´ the following insights and requirements are gained and later used in the design phases.



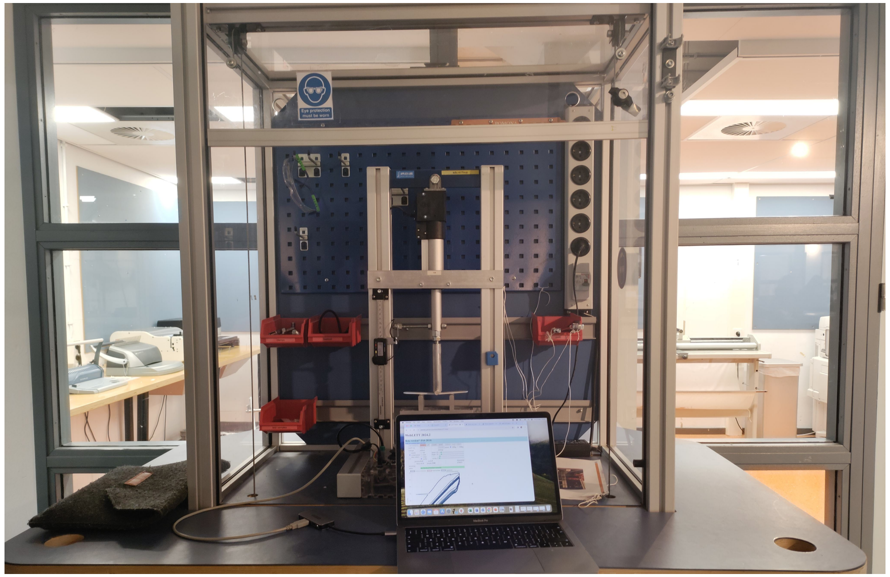
3. LETT

Currently there is an experiential setup in use at IDE that allows students to test and understand the engineering principle of yield and tensile strength. This low-end tensile tester (LETT) for educational purposes is designed by Welling (2014) for his masters theses. He designed the LETT specifically for student from IDE. After Welling's design, the IDE staff have refined and iterated on the design. Currently 20 LETT testers are in use at IDE. How this machines functions (within IDE) is very valuable for this project and is therefore thoroughly analysed.

The reason that this machine is developed in-house is that there were not enough (easy to operate) tensile testers for students available. This type of tensile testers is commercially available, however they are very expensive. Before the LETT, IDE students in the bachelor phase only got to observe a test, after which they had to analyse the results. The result is that most students, after only a couple of years, no longer remember anything about material testing, let alone remember how to calculate material characteristics like the Young's modulus or the yield strength. With this machine, IDE students do not only get to observe a test, but conduct and experiment with the machine. (Welling, 2014)

Observation

To assess the machine's performance when used by students, Kiet Stiemer and I conducted a 'Direct Non-participant Observation'. This approach means that, as researchers, we did not interact with the students while they were using the machine. The observation was guided by the principles outlined by Ciesielska et al. (2017) and took place during the Materials and Manufacturing workshop. The aim was to gather insights and inspiration for developing our own experiential setup. Additionally, we interviewed students who used the LETT independently (outside of a course workshop) in the central hall. The insights gathered during this observation are visualized in appendix A.2.1. An textual overview is stated in the end of this chapter.

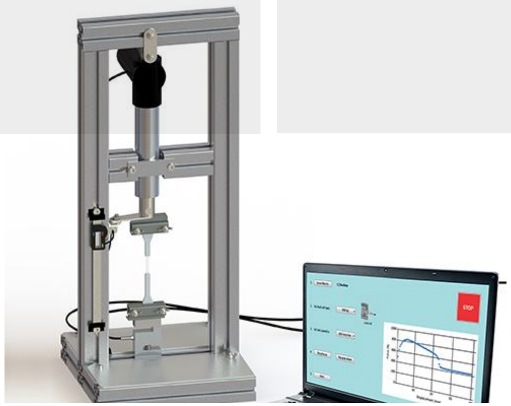


Simplified customer journey + barrier analysis

By using a customer journey map (Van Boeijen et al., 2014b), insights can be gained into the steps and barriers students encounter when using the LETT.

	Pre-LETT	Accessing LETT	Working with LETT	Post-LETT
Physical barriers	• LETT is only available at IDE during study hours.	• Tries to use LETT, but it is locked • Go, to **IDE Help desk*** to get key • Hand in TU campuscard (not always at hand)	• LETT is incomplete or broken • You need to provide your own material • One person can access the machine	• Results are stored on one computer
Mental barriers	• User has/wants to do tensile test but is unaware that the LETT exists. • User does not know how the machine works and therefore avoids it.	• Having to ask for they key • When receiving the key, the students is and feels responsible for the machine and key.	• Does not understand LETT	• Unsure if tests that are conducted show the right values.
Reason why	• Not visible in central hall. • No overview of tools available. • No awareness due to poor publicity	• IDE is afraid that students will treat the LETT irresponsible and possibly steal parts.	• Students do not read manual	• Only one person operated the machine

*This analysis shows that it's an important step is the IDE help desk. To dive deeper into this another barrier analysis is made for the IDE helpdesk in specific. This can be found in appendix A.2



LETT analysis insights and requirements.

- dv-3 User-friendly design
- dv- 4 Exciting design
- dv-5 Accessible design
- vv -1 Low investment costs
- vv - 2 Low maintenance
- vv- 3 High return of investment

- Insight - Nobody reads the f*cking manual
- Insight - If the setup is digital, make it web-based. Downloading software is a hassle.
- Insight - The priority should be the learning goals, not on extra tasks like tightening bolts or downloading software.
- Insight - Making a setup that is accessible from all sides allows more students to feel engaged.
- Insight - Create spark/awareness to use the setup will enable more students to use the setup, leading to a more valuable design.
- Insight - Many resources (tools and machines) are not displayed or hard to find as a first year (or even master) student. There is not even a website with all the things that you can borrow at the service desk. You have to hear from your peers that you can borrow or use it.
- Insight - By creating social control less things will disappear and be stolen.
- Insight - Create overview of available (and missing) parts.
- Insight - Reduce part cost to make it easy to replace parts, have stock and prevent students from taking it home.
- Insight - A multi-functional setup can significantly enhance return on investment. For instance, it can generate four times more value while only doubling the cost. Additionally, it offers the opportunity for incremental development; different functions can be added over time, allowing the setup to evolve and expand within the educational system.

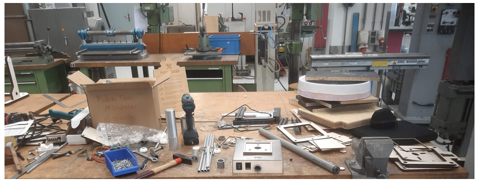
- New Requirement - 4. >80% should be able to use the setup without a manual.
- New Requirement - 5. The time to setup the setup should be smaller than using the setup.
- New Requirement - 6. The setup should be accessible from all sides.
- New Requirement - 7. The setup should be able to be used by other faculties and therefore online displayed.
- New Requirement - 8. The setup should be visible in the current daily workday of a student.
- New Requirement - 9. Missing parts have to be discovered before using the setup.
- New Wish - 10. Low parts cost (later define what low is)
- New Wish - 18. The setup is multi-functional
- New Requirement - 11. The setup should be versatile and educate students with different engineering principles

4. Context

During the IDE bachelor, learning opportunities get facilitated in different ways. All providing information and some enabling hands on learning. These are mapped out below. Context traits are stated and reasons are provided why these contexts are interesting or un-interesting for this project. This is essential to determine what the surrounding will be of the setup and group sizes.

Where: **IDE studio's**
What: Educational setups
When: During course

IDE has studio's that function as class rooms. This context is perceived as a safe space where bachelor students spend quite some time. The down side is that when you have to divide 15 educational tools over 15 studio´s you still only have one tool per studio with 20 students. And on top of that you need 15 teachers. This makes it hard for the whole studio to work with it. Therefore more experiential setups are better.

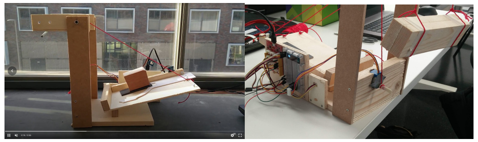


Where: **PMB**
What: Machines & Hand tools
When: 9:00 - 17:00

The PMB is the model-making and machine lab of IDE. With nearly every machine and tool available, you can create almost anything. However, the capacity is limited. 350 Students at once in the PMB is not possible. Therefore this design has to be designed for another context.

A student questionnaire (see Appendix A.4) revealed that many students primarily use the simplest and most accessible tools, like the 3D printer and laser cutter, leaving many other tools unused. There are some disadvantages to this workspace. Tools are expensive and dangerous, strict supervision is necessary, sadly this also reduces accessibility. The drills are behind the counter, do you want to 3D print, then you have to sign up for a list. If people know how to 3D print you can make most things, so students will not learn about other manufacturing methods and materials.

A staff member programs the CNC mill, the laser cutter or control the vacuum former, the sawing table or the angle grinder. All with the best intentions but limiting the students hands-on experience and overall accessibility.



Where: **Flex workshop**
What: Hand tools
When: When lockers are open- during course

The flex workspace can handle a lot of people at once allowing the workspace to be used during courses. Next to that it is open during study hours. Random building materials are also available. Sadly, All tools are locked during standard hours, limiting the potential of this space. An initiative by students was to put all tools on the wall as a rebellious act and as experiment, to see if it would last. Up till now 3 months, 80% still hangs on the wall.

Where: Accesible via Helpdesk
What: Products & Machines like the LETT
When: All the time

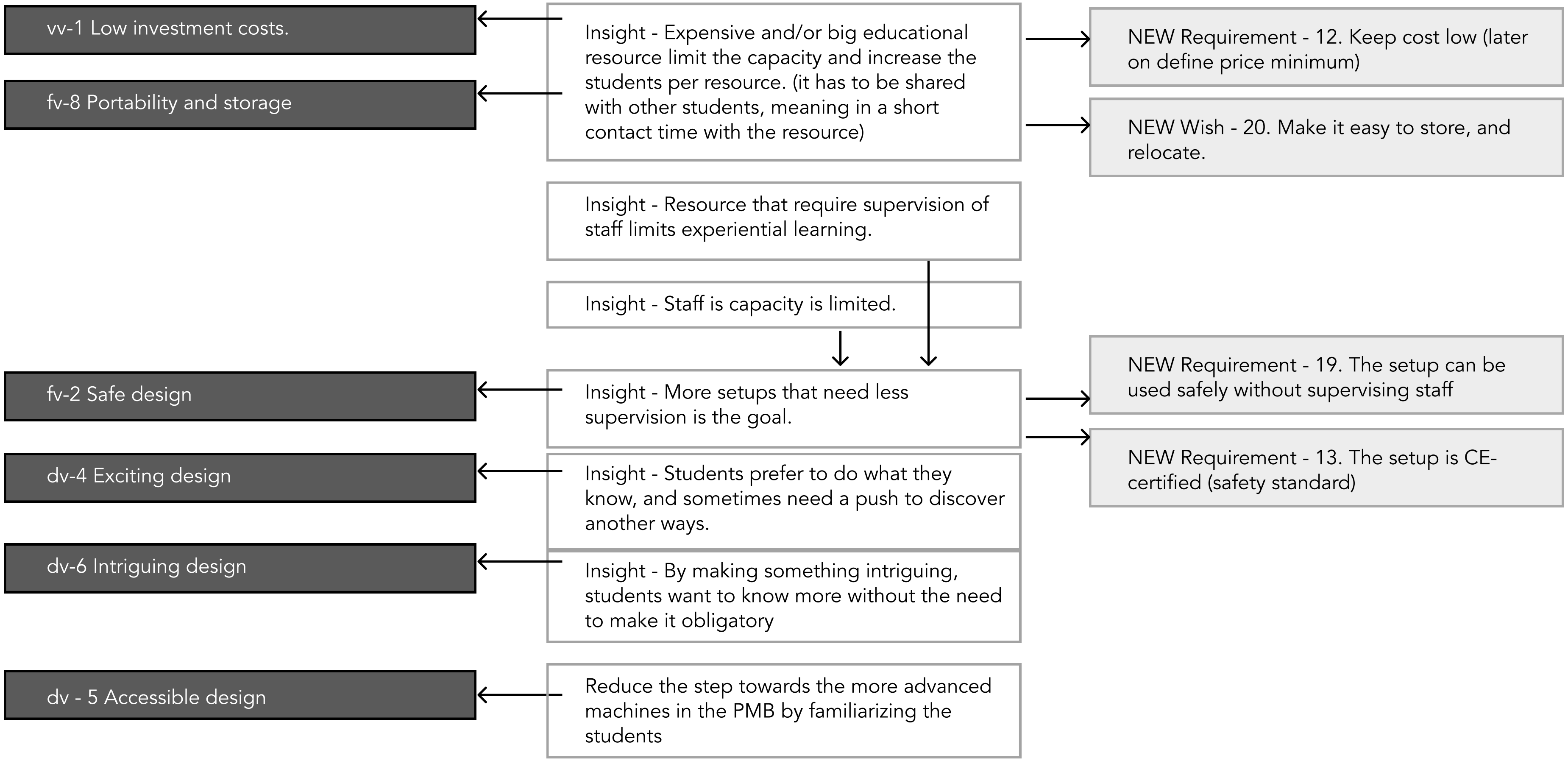
At the information desk at IDE can you borrow different tools and products that you can use during you design process. For example, lights, camera's and during corona even 3D printers to bring home. This systems allows students to work and experiment with it and is in line with the experiential approach. However, the customer/student journey (see appendix A.2) shows that this 'borrowing process' has it's limitations and barriers for students . This context does, aligns with an experiential approach and therefore we think that this project has to be designed for this environment.

Where: Lecture hall
What: **Demonstration**
When: During a lecture

A conventional form of education is a lecture. A good way to educate for a big group of students at the same time. By adding a demonstration during these lectures, an extra sense gets stimulated, namely your eyes, and sometimes students can even try it. This adds a new dimension to lectures. Almost always is this perceived by students as a positive add on (Milner-Bolotin et all. 2007). However, it does not connect to the experiential learning approach where students are actively involved in the learning process. 350 students on stage with one demonstration is not possible. Therefore is this context is out of scope for this project.

From this we can conclude that there are several fruitful contexts where this setup can function. Capacity is one of the biggest issues. This can be due to the limited amount of resources (only 20 LETT machines available) or not enough educators or safety supervisors.

Context insights and requirements.



5. Engineering bachelor courses

'Develop an experiential setup which can be used to enhance learning in the engineering bachelor courses' To do this it is important to understand the structure and the goals of these courses. This project focuses on three bachelor engineering courses*. Materials and Manufacturing (M&M), Advance Prototyping (AP) and Understanding Product Engineering (UPE). The goal of this chapter is to discover where an experiential setup could enhance learning. This research helps with the choice if this project should focus on only one of the engineering courses or if all three will be in the scope of this project. For the final subject and scope choice, please be referred to 'subject choice' on page 25. Here is a short description of the courses. For the full course description and learning goals, please be referred to Appendix A.4 & A.6.

UPE

The "Understanding Product Engineering" course is a first-year course in the first quarter. The course focuses on understanding technical principles for designing physical products. The course involves analysing existing products to apply these principles in future designs, considering materials, production processes, and technical feasibility. Through analysis and abstraction, students will gain insights into how different aspects impact product design. UPE applies a PF approach. (see chapter 'Educational Approaches' if you do not know what that is.

M&M

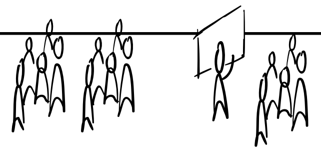
The "Materials and Manufacturing" focuses on sustainable alternatives to carbon-based materials, using waste streams like coffee and fruit waste. Students will learn to create and test products such as lunch boxes and phone cases. It teaches tools for designing, modelling, and testing new materials, highlighting the impact of manufacturing techniques and material selection on product performance.

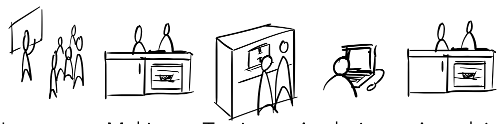
AP

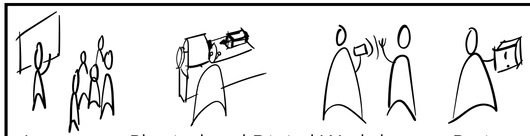
The "Advanced Prototyping" course equips you as the name implies; with advanced prototyping skills, techniques, and materials to create functional and aesthetic prototypes. It covers interdisciplinary knowledge, practical skills, and critical and creative thinking through lectures, workshops, and projects. You will learn to apply the right techniques at the right stage of the design process.

	UPE	M&M	AP
Hours	133 Hours Obligatory	133 Hours Elective	800 Hours Minor
Capacity	350+ Students	30-120 Students	25-75 Students
Approach	Productive failure	Experiential learning	Experiential learning

Work flow


PF Workshops + Lectures


Lectures + Making + Testing + Analysing + Appplying

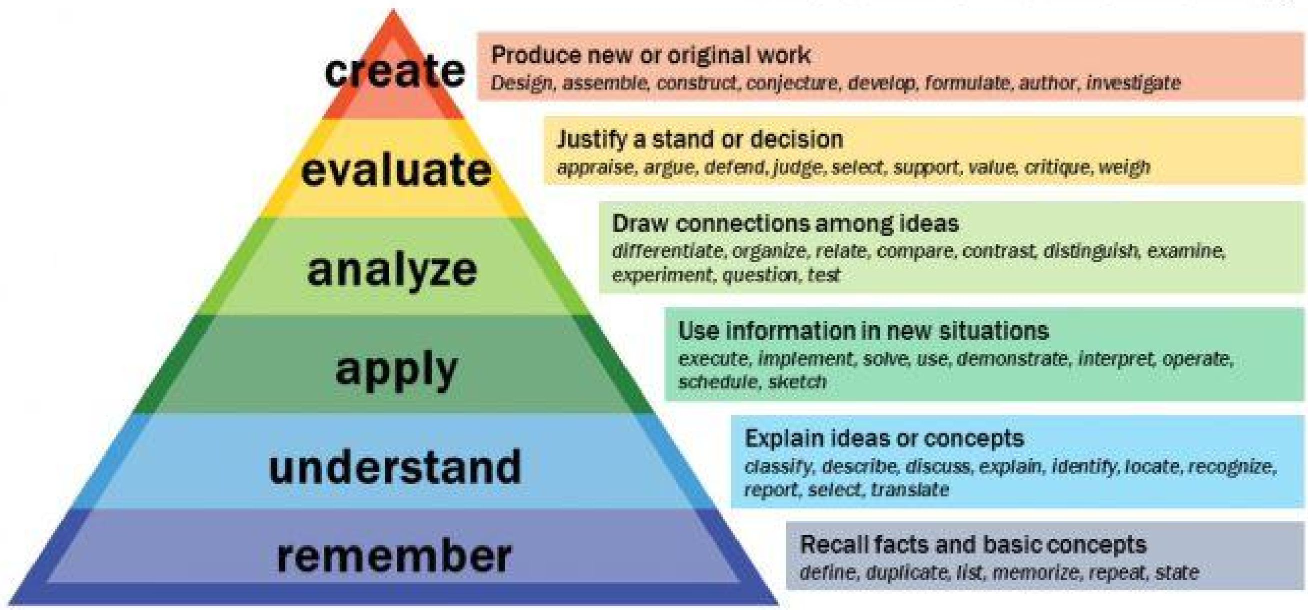

Lectures + Physical and Digital Workshops + Project

*The course overview in Appendix A.3 shows that there are more courses labelled as Technology or Engineering. Most of these courses focus more on the digital side of engineering, such as programming. However, this does not mean that engineering is not required or taught in these courses. For this project, it is out of scope.

To make a more informed choice, we needed to delve deeper into the courses. This was achieved by analysing the overlap between final attainment levels (OER), learning objectives (LO), course materials, exams, and research papers related to the retention of basic engineering principles. In collaboration with Kiet Stiemer, we created a comprehensive visual overview to identify gaps. This overview is detailed in Appendix A.5 for the UPE course and Appendix A.7 for M&M and AP.

All objectives are categorized according to Bloom's Taxonomy, a hierarchical classification system used to organize educational learning objectives and skills. This framework, established by Bloom in 1956, helps educators design curricula, assessments, and instructional methods that foster higher-order thinking and deeper understanding. The visual from McDaniel (2010) provides a clear overview of this taxonomy.

All courses are quite well structured and there are no big knowledge gaps. However, some objectives did not align with the exam questions or course materials at their respective Bloom levels. The most important insights from this analysis are summarized on this page.



vv-4 Versatile and Scalability

fv-7 Integration in IDE education

vv-6 - Enhances education results

Insight - The objectives from AP and M&M require a higher Bloom level. For example applying the knowledge while UPE only has to make the students understand. This means that it would benefit the experiential setup if it can be used to educate on different Bloom levels. Teaching students to understand but also to use it and apply the knowledge on the setup.

Insight - Time is limited in the UPE and M&M course UPE = 350 Students in one afternoon.

Insight - Product structures and connection methods are currently not thought in UPE. It is however expected in learning objective (LO) 1.1

Insight - Balanced sustainable judgement on ways of production, recovery processes and energy sources is not thought in UPE. It is however expected in learning objective (LO) 1.7

Insight - In the UPE course, manufacturing is only tested on Bloom level 2. While the OER expects level 3.

Insight - Currently in the UPE course manufacturing methods can be looked up on the software that is available during the exam (open-book exam) and therefore score high without testing proper understanding.

Insight - NVM Lines are mostly tested on Bloom level 2 “Understand”, While LO 1.2 and 1.5 expect Bloom level 3 “Apply” in the UPE course

Insight - M&M product results are often ‘2D’. Such bags, phone cases etc. Creating a setup that can be used to experiment with different product structures (3D) could give more insights.

Insight - Test finite element analysis or calcualted load and breaking in real life product (not just a test sample) but also its more complicated shape.

NEW Requirement - 14. To make the setup applicable for several courses it should educate on different Bloom levels.

NEW Requirement -15. 350 Students can experience the setup in one afternoon (4 hours).

NEW Requirement - 16. The setup should educate on the subject product structure.

NEW Requirement - 17. The setup should educate on the Manufacturing methods and materials

NEW Requirement - 18. The setup should educate on the subject NVM lines, forces and deflection.

6. User test - Questionaire

In this theses, all research involving test with the target group is outlined with a black line and the colour of the chapter. These researches are structured as mini stand alone research papers with their own introduction, method and materials section, results, discussion and limitations.

Students current perception of IDE education and knowledge of engineering principles.

Kiet Stiemer and Robin Taen

Introduction

To understand students' current perceptions of IDE engineering education, the workflow of the UPE course specifically, and the current experiential machine (LETT), as well as their engineering knowledge and retention, Kiet Stiemer and I conducted a questionnaire. The questions are based on the learning objectives from the UPE course (see Appendix A.4).

The primary goal of the questionnaire was to identify the most challenging subjects and determine which could benefit most from an experiential machine. In addition to previously used UPE exam questions, we analysed the learning objectives ourselves and formulated more practical, real-life questions that design students would encounter and that we consider essential. Some of the results were surprising. The secondary goal was to 'zoom out' and discover students' perceptions of experiential learning (e.g., with the LETT) and their educational approach preferences.

This study is significant as it provides insights from the students' perspective. Since it is not an officially scored exam, we hope to discover if students have truly picked up the basic engineering knowledge rather than just passing the exam questions. The subsequent sections of this paper will present the materials and methods, present the findings, results, and conclusions. As this is a mini-research project, recommendations for future research will be left out of scope.

Materials and Methods

This study was conducted by a voluntary online questionnaire. The questionnaire was structured to be completed in approximately 5 minutes. Since it is online and short it allows participants to complete the questionnaire at their convenience from any location. There are open and closed questions. Participants were recruited via convenience sampling, with the questionnaire distributed through bachelor WhatsApp group chats and by direct solicitation in the central hall of the IDE building. A total of 23 IDE students participated, comprising 26% first-year students, 30.4% second-year students, and 43.5% third-year students, with no distinction made by gender.

The structure of the questionnaire was as follows; Firstly, questions about 5 engineering subjects are asked. All based on the UPE learning objectives (See appendix A.8 for these correlations); Each subject containing 3 sub-questions. The 5 subjects;

- Materials behaviour and understanding
- Plastic manufacturing processes.
- Material and manufacturing choice and determination. (Example on next page)
- Moment of inertia and basic statics.
- Internal forces and deflection. (NVM)

Secondly, personal questions will address their perceptions of IDE education, their current educational status, and their experiences. For the full questionnaire and its questions, please refer to Appendix A.8. On the following page you see an preview of the questions.

Preview of content questions;
Chapter 1 out of 5
Material and manufacturing choice and determination

Gegoten staal (cast iron) BBQ

Plaatstaal Aluminium BBQ

Plastic speelgoed BBQ

Je baas wilt 50 bbq's laten maken en verkopen als 'special product of the month'. Welk type BBQ is het goedkoopst en snelst om te laten maken?

- ○ Gegoten staal BBQ
- ○ Plaatstaal Aluminium BBQ
- ○ Plastic speelgoed BBQ

Welke BBQ vind jij het meest duurzaam en waarom?

Tekst lang antwoord

Van welk materiaal is deze mok gemaakt? *

Je verwacht dat deze mok is gemaakt van Aluminium, hoe zou je dat testen en analyseren?

Korte antwoordtekst

Preview perception questions:
3 out of 10.

Waar op deze schaal zie je de bachelor IO? *

	1	2	3	4	5	6	7	8	9	10	
Theoretisch	○	○	○	○	○	○	○	○	○	○	Praktisch

Waar op deze schaal zou je de bachelor IO liever hebben? *

	1	2	3	4	5	6	7	8	9	10	
Theoretisch	○	○	○	○	○	○	○	○	○	○	Praktisch

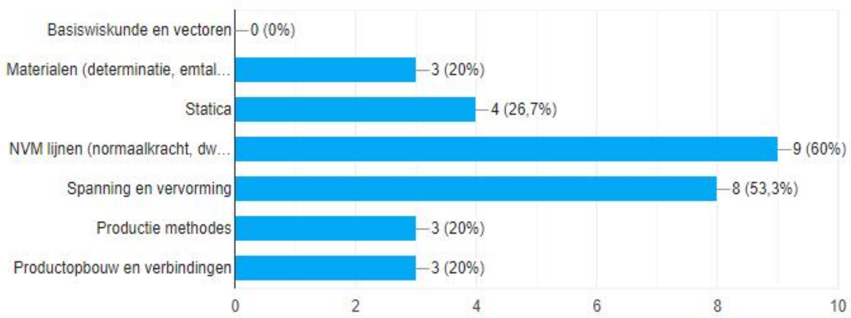
Kruis aan welke onderdelen van UPE je het moeilijkst te begrijpen vond (maximaal 3).

- ☐ Basiswiskunde en vectoren
- ☐ Materialen (determinatie, emtalen, polymeren, dichtheid, recycling)
- ☐ Statica
- ☐ NVM lijnen (normaalkracht, dwarskracht, buigmoment)
- ☐ Spanning en vervorming
- ☐ Productie methodes
- ☐ Productopbouw en verbindingen
- ☐ Anders...

Results & Discussion

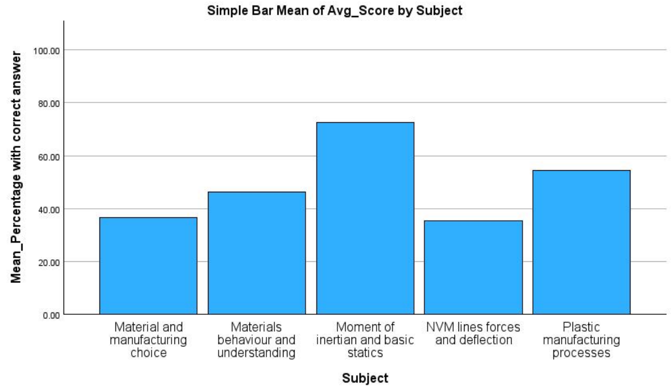
The main objectives of this questionnaire are to identify the most difficult subjects and determine which one would be best suited for an experiential learning approach. This is attained in two ways, namely: through the analysis of the questionnaire results from content-based questions and perception questions.

Students perception of most difficult subject in the UPE course



The results show that all subjects except 'basic math and vectors' are perceived as being difficult. 'NVM lines (internal forces)' and 'tension and deflection' are perceived as the most difficult. These subjects, as well as statics, frequently require the use of mathematics. All of the students who reported (see appendix A.9.1) struggling with 'NVM lines (internal forces)' and statics indicated that they did not understand the subject matter at all, that "it was hard to deduce" and that "the subject was too abstract." Some students also indicated that the volume of information in 'manufacturing methods' made it difficult to understand, as they had limited experience in this subject area.

Students content-based question results, per subject

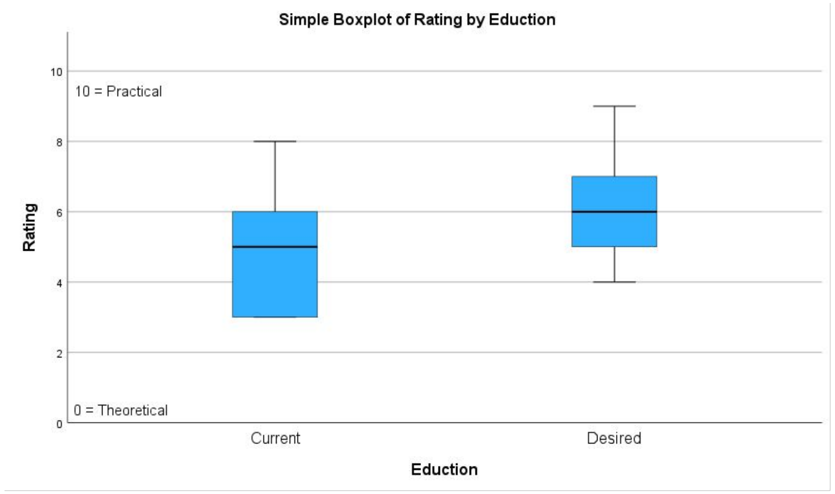


Based on the results of the content-based questions we see that the mean of all subjects score low on average. Basic questions about statistics and moment of inertia score higher. But this is all depending on the difficulty of the test question. These test questions were made with the personal view and experience from the researchers (us), what we think an IDE students should know. Since there are also open-ended questions in the questionnaire it is interesting to look at these results. Since this is not a scientific paper the most interesting and relevant insights are presented in table 1.

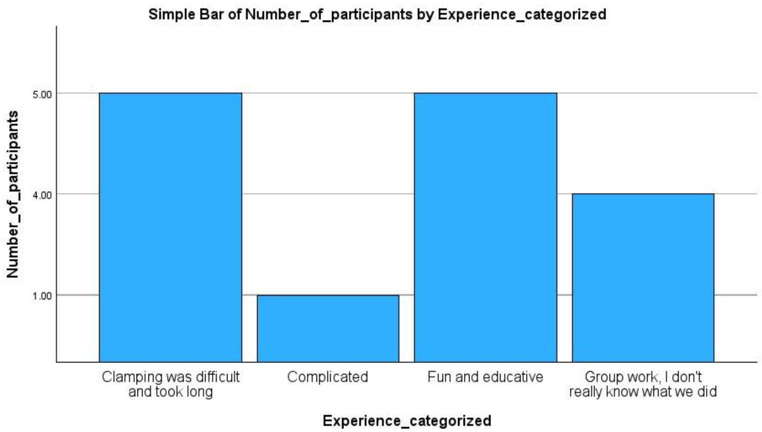
Table 1 insights

Insight - 'Feel' for materials such as metal is scoring low. 75% of the students expected cars to be made out of ≥3mm think steel. (real life 0.8-1mm)	Insight - Reduce abstractness in 'NVM lines (internal forces)' subject.
Insight - Knowledge about vacuum forming scored low. Many people were not familiar with this manufacturing process.	Insight - Normal, Vertical Moment lines are only tested in the conventional way which students do not fully understand and experience as extra difficult.
Insight - Hands on feel for materials and manufacturing processes and their opportunities and limitations for embodiment design.	Insight - Calculating with deflection is seen as difficult, however they do understand that there is deflection and where it will occur in realistic situations.
Est. Requirement - 17.The setup should educate on the Manufacturing methods and Materials	Est. Requirement - 18. The setup should educate on the subject NVM lines, forces and deflection.

All results can be found in the appendix A.9. This paper will elaborate on the findings that are most relevant for this project and it's conclusion.



Overal a bigger percentage wishes to have more practical education.



The students perception of the LETT aligns with our LETT analysis. A big percentage liked the experiential machine and thought its attributed to education. Another big part thought clamping took very long or did not really know what happened since they were working on it in groups.

After this analysis it is evident that students struggle with all subjects and could benefit from support through an experiential setup. The key to the success of this project may not lie in identifying the perfect subject to improve, but rather in determining how to improve it effectively.

We can also conclude that students prefer a more practical and experiential approach in IDE education.

Insight - Students prefer a more practical/hands-on approach in IDE education.

↓

dv-7 Enhancing education experience

Limitations

One limitation of the study was the inclusion of students from different academic years. Focusing on a single cohort, such as students who completed the UPE course six months prior to the study, might have provided more targeted insights.

Additionally, the questionnaire was very broad, encompassing a variety of open and closed questions. While this approach provided valuable insights, it made scientific analysis challenging.

7. Subject choice and course scope

After this analysis it is evident that all subjects could benefit from support through an experiential setup if this would improve the results. The key to the success of this project may not lie in identifying the perfect subject to improve, but rather in determining how to improve it effectively. Therefore a subject choice is made based on the following arguments.

This setup will focus on manufacturing processes and aims to demonstrate its opportunities and limitations.

Reasons for this choice;

1. Manufacturing of products is a subject of which focus is greatly reduced during the last years. Previously, bachelor students had at least one course of 10 weeks (200 total) on this subject. However, it has now been reduced by 93% (1 week for 13 hours = 13 hours).
2. The analysis showed that all courses could benefit from manufacturing education and resources.
3. My personal interest is manufacturing and I expect that I am able and competent to develop a setup for this subject. I also see many peers that really struggle to create feasible designs. I think that improved manufacturing and experiential setups on this subject can really be beneficial and of big value for IDE.
4. My peer Kiet Stiemer is working on the same project and we want to differentiate; he will focus on NVM lines, forces and deflection.

This means that other subjects will be out of scope for this project and will therefore be removed from the requirement list.

Chosen subject

Established Requirement - 17.The setup should educate on the Manufacturing methods and Materials

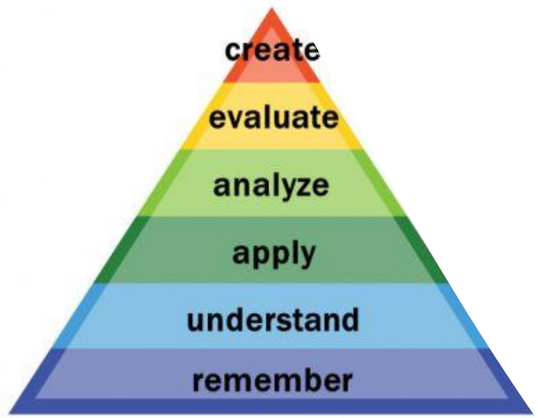
Out of scope

Established Requirement - 16. The setup should educate on the subject product structure

Out of scope

Established Requirement - 18. The setup should educate on the subject NVM lines, forces and deflection.

As stated above is it expected that all courses can benefit of an experiential setup focused on manufacturing. Therefore also all courses will be in scope. However, the main focus during this project is UPE since this is the course that could benefit most. M&M and AP showed that the setup should be designed in a way to facilitate learning on different Bloom levels. This means that the setup should function in a context where its goal is to understand a manufacturing process but also to analyse what its limitations are or to create and evaluate the result.



Recap Analysis

The analysis phase made clear what the context of the experiential machine is, why it has to be developed and what the subject of focus is. With this the assignment is reformulated and specified;

In chapter '2. Educational approaches' the reasoning for this educational approach was given. In chapter '3. LETT' many insights were obtained in the experiential setup that is now in use (the LETT).

The goal during the analysis phase
'Develop an experiential setup which can be used to enhance learning in the engineering bachelor courses'

In chapters ´4. Context, 5. Engineering bachelor courses and 7. Subject choice and course scope´ it becomes clear how the experiential setup can contribute to the courses.

Chapter ´7. Subject choice and course scope´ argued what kind of subject this experiential setup will focus on.

Chapter '6. User test' showed where education needs improvement and what students perception is of current education.

Statements V1

The goal during V1
"Provide students with an experiential setup to learn the reasons why materials and their manufacturing methods are used."

Why?
The overarching goal during the analysis phase In short; Real concept understanding and am intuitive 'feel' for materials and production processes seems to be missing in the obligatory courses.

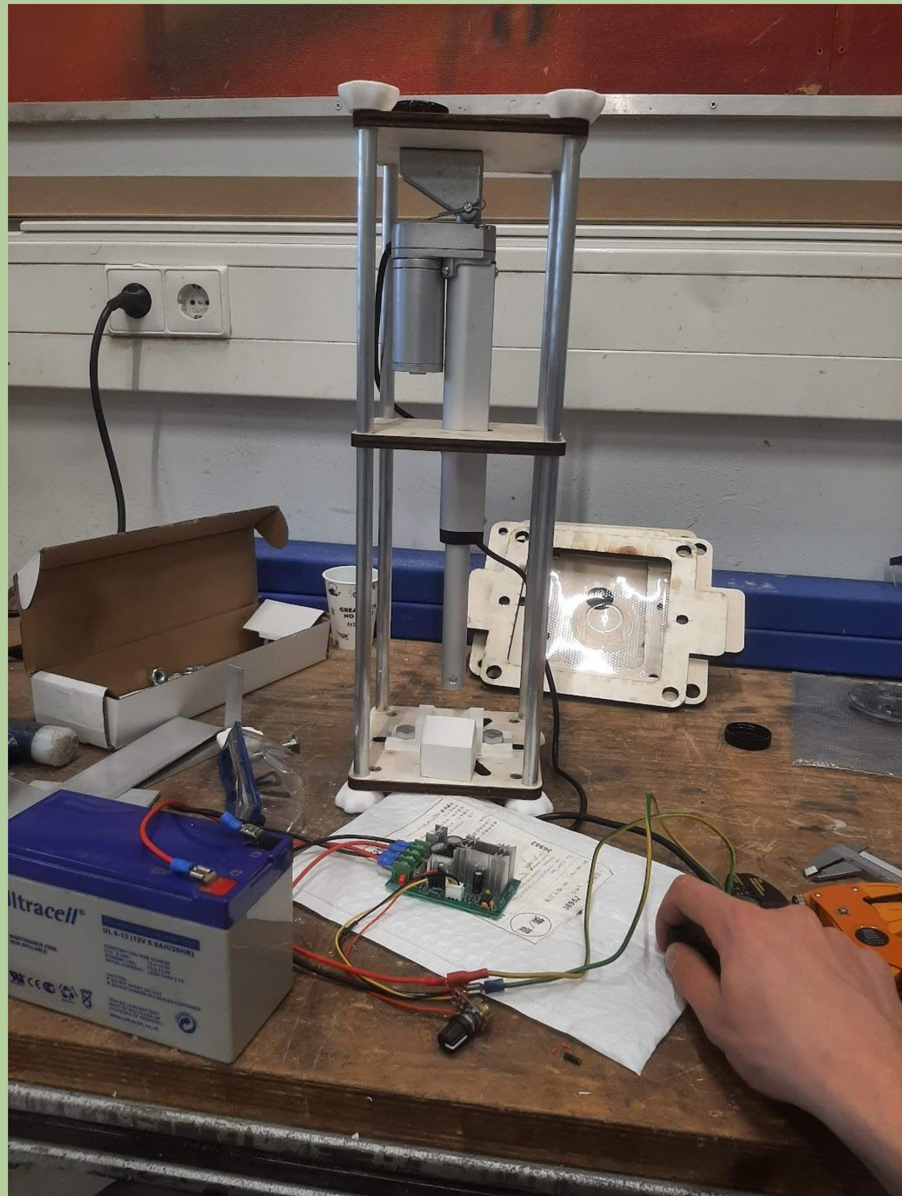
Focus
The focus on this prototype in specific is to research if a Low-fi (Cheap) setup is feasible and if it can give students a feel for different production methods and materials. The focus will be on 3 common small scale production methods.

How?
By making a small sized production setup that can be transformed into different production processes, students can experience the process first hand. By letting the students build the machine themselves they will touch all parts, placing them in different locations, and therefore feel and understand the functionality, By simplifying the machines, part count and cost can stay low.

For the full list of requirements and value characteristics please be referred to appendix A.10

Prototype V1

Low-fi machines, what is possible?



1. Intro prototype V1

After the analysis, the design goal is further defined and a lot of criteria are established. After an ideation phase the most fruitful idea was to 'minimize' manufacturing machines into experiential setups. This allows students to experience the process first-hand, free from the pressure of achieving perfect results on the first try (due to material high costs or deadlines), high costs or safety risks.

What makes the prototypes in this project unique compared to what's currently on the market is the design focus on education and the innovation flow. These prototypes will develop in a completely opposite direction compared to conventional market development. Innovation flow, is a made-up word combination. It strives to describe the way in which development occurs. For example: early laser cutters, developed in the 1960s, large, complex, and extremely expensive machines used mainly in industrial settings. These machines required significant technical expertise to operate and maintain.
In recent years, laser cutting technology has been miniaturized and simplified for hobbyists and small businesses. The same applies to plastic injection machines. Designed with the focused on mass production and highly advanced, but they come with significant downsides. They are often bulky, expensive and require technical expertise. To make these machines accessible for smaller companies or even consumers, cost and size are reduced.

Innovation typically starts with the industrial machine, where the focus is on shrinking its size, simplifying its functions, and substituting materials until the price becomes affordable for the consumer.

Despite these changes, the innovation process remains focused on the end product and the machines functionalities. I refer to this approach as the "conventional" innovation flow. (See the next page for a visual representation).

Another ingenious innovation flow that we see happening is that of the precious plastic community (Precious Plastic Community, n.d.). Their design focus is to make plastic recycling accessible for small/emerging markets. Sadly these machines do not meet the safety standards and does not have the capacity for big student groups. The way how they simplify machines has been a true inspiration during the process.

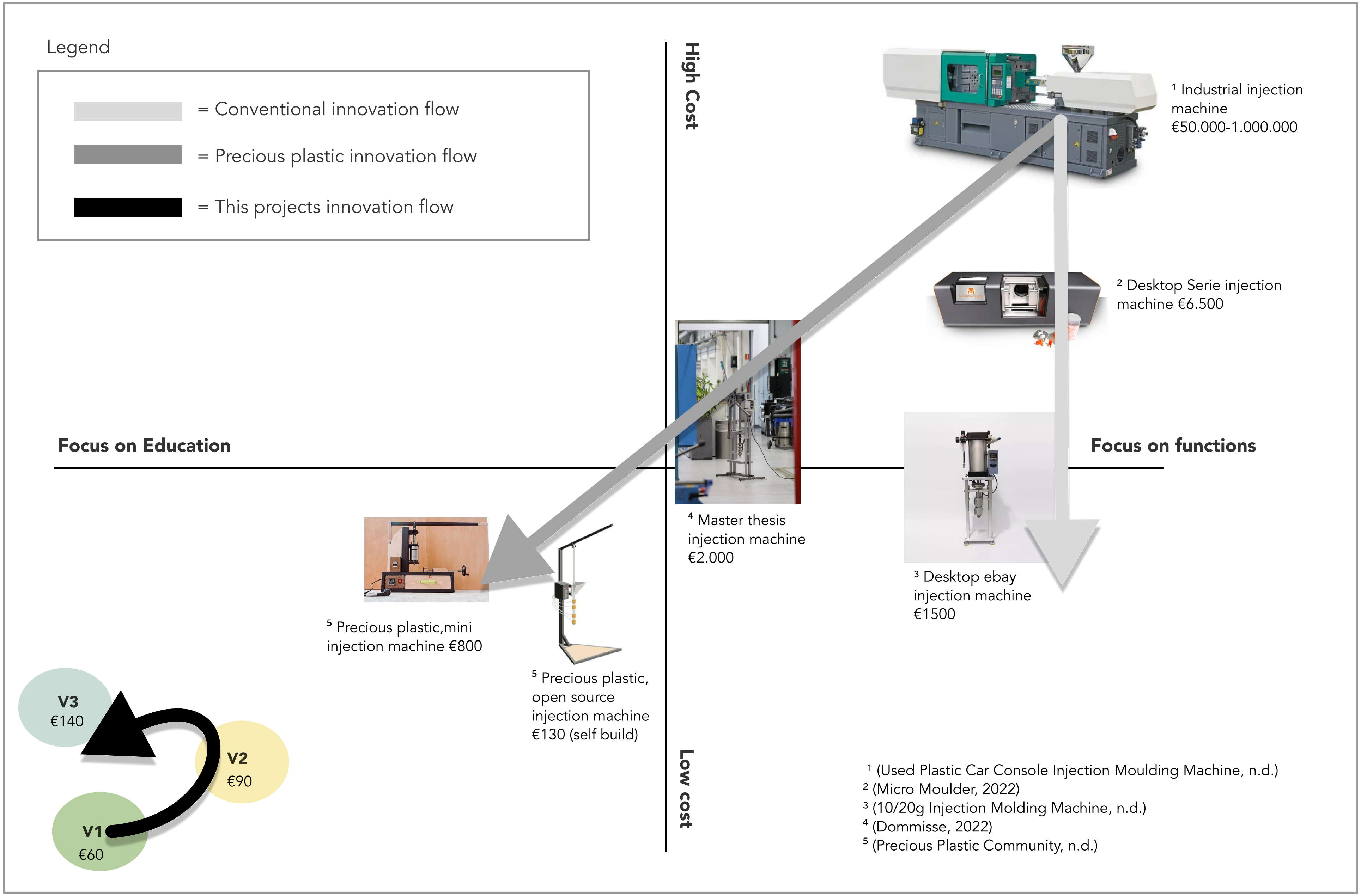
The innovation flow of this projects starts in the opposite corner. How can we educate students with as cheap resources as possible. During testing it becomes clear that too low quality machines and its results are not sufficient to educate students. Therefore the focus in prototype V2 moves more towards the machines functions and results. V3 focuses again more on the educational aspects of the machine, with that comes some increased costs. However, it won't loose its original goal 'education'.

While prototyping it is essential to be very aware how parts will be made in the final design. The prototype might satisfy its goals as 3D printed machine while the final design will need to be made out of aluminium and be milled, and expensive process. Cautious design choices should therefore be made.

fv-1 Making real products/parts ← Insight - The way to make students experience manufacturing methods and materials is by letting them use them. → New Requirement - 21. The prototype makes real products/parts

vv-6 Different focus than market alternatives ← Insight - With the pure focus on a low cost - educational setup, the design can differentiate from the market and create more value. → Established Requirement - 12. Keep cost low (later on define price minimum)

fv- Production ready ← General Goal - The goal is to make prototypes that gradually evolves and can be manufactured at the end of this project. → Established wish - 40. For prototype V1 the aim is Technology Readiness Level (TRL) 3 'Experimental proof of concept'

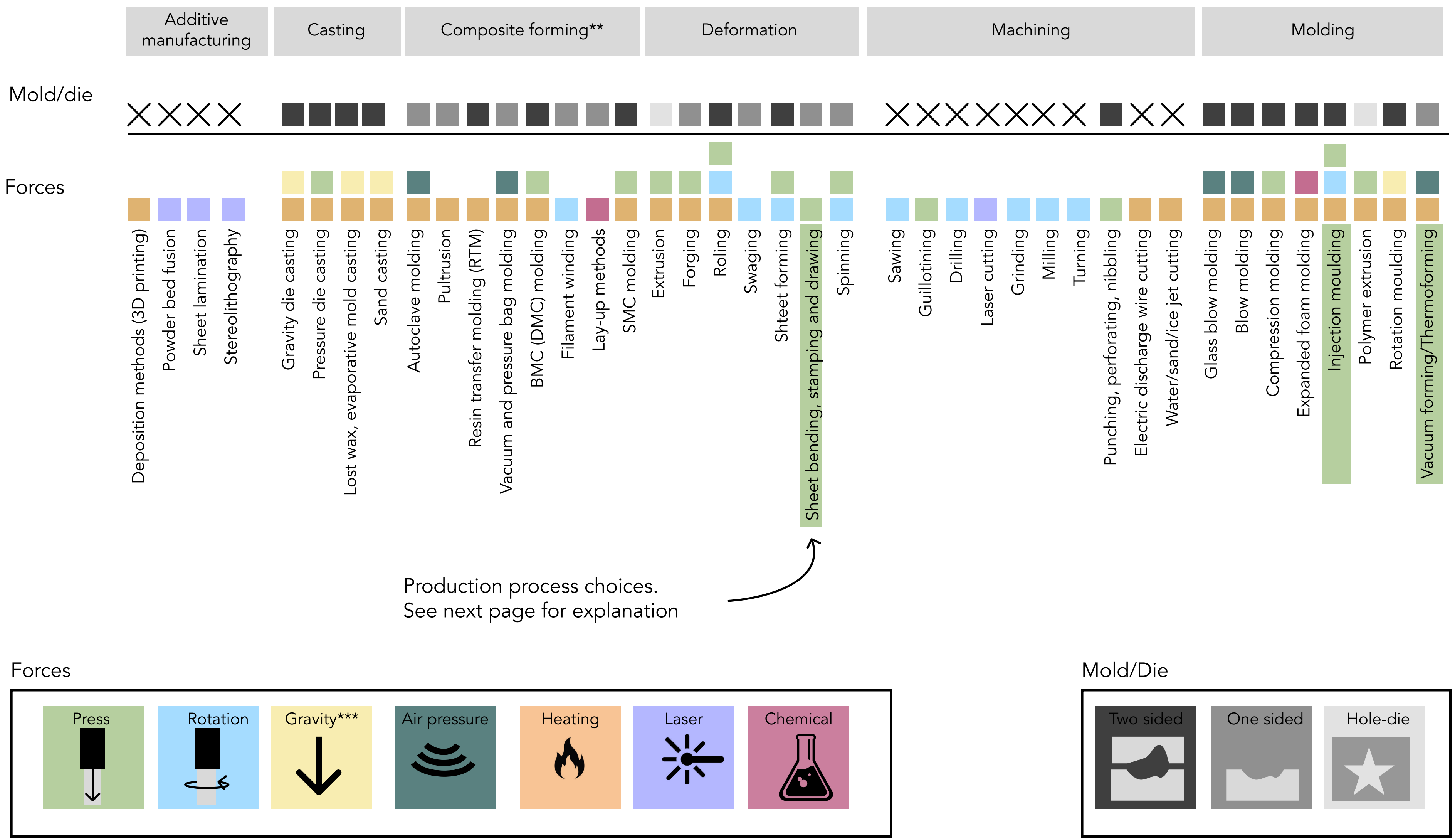


Insight - The injection mold machines are mostly more than €800. The self builds from Precious Plastic is €150. One configuration should therefore be doable for that price.

See chapter: 6 Designer Reflection V1 how this changed established requirement 12, about cost price.

Manufacturing methods*

This infographic shows almost all manufacturing processes and their forces + molds/dies. This is used to choose the productions processes in prototype V1. Many machines have overlap in the type of forces or molds that are used.



*'Joining and surface treatments' such as adhesives, welding, fasteners, painting or anodizing are out of scope.
** Very rarely used processes are left out of scope.
*** On earth, there is always gravity. This force is only used when its the primary force of the process.

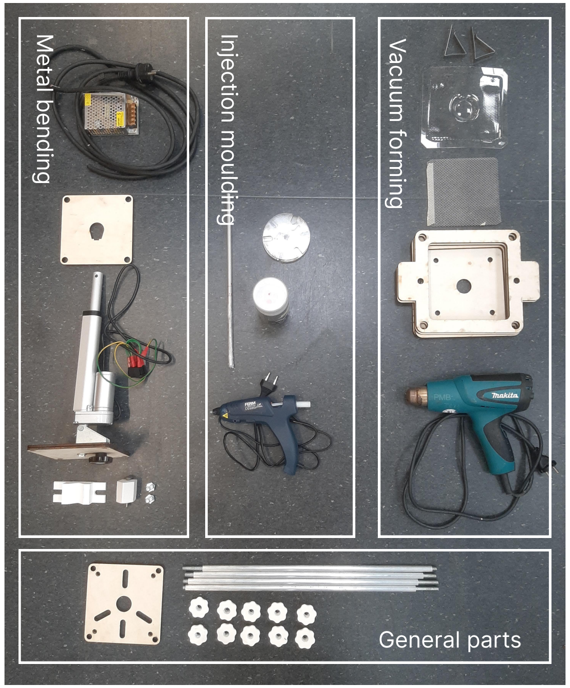
Production process choice

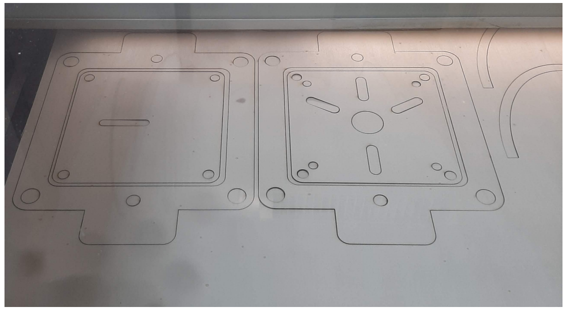
In this prototype (V1), three production methods are selected. The requirement from the analysis phase show that the machine has to be versatile and costs-effective, which led to the decision to make the setup modular. Two of the manufacturing methods, in my opinion, did not fully showcase the potential of this modular design. Additionally, developing more than three methods would have made it difficult to fully explore and validate each configuration. Therefore, three manufacturing processes were selected.

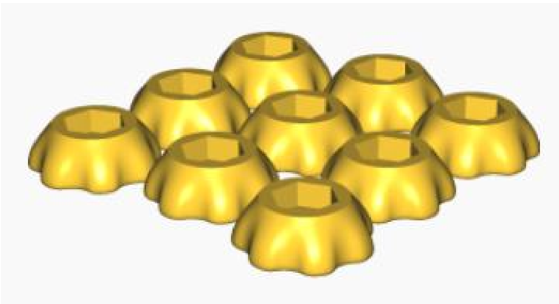
This choice for vacuum forming, metal bending and injection moulding is based on several insights;

- The infographic above shows that manufacturing methods have a lot of overlap in the machines and molds/dies that are used. By picking 2 production methods with 1 mechanical force we can show that one part (a press) can used in different configurations.
- The safety risks of a press (1000N) causes less safety risks during development than something that is rotating/spinning.
- Knowledge of vacuum forming is something that scored low in the user questionnaire. Many people were not familiar with this production process, however it is a very good prototyping tool and can therefore need more impact.
- Vacuum forming has been done with relatively simple tools before (BrainfooTV, 2017). These are however very ‘do it yourself (DIY)’ without the focus on education or expensive.
- Metal bending is a production process that is used a lot in a professional context, yet little students are aware of the manufacturing process and miss the ‘feel’ for these processes and materials. Based on the insight from the user questionnaire.

Insight - manufacturing methods actually have a lot of similarities. By picking 2 production methods with 1 mechanical force we can show that one part (such as a press) can be used in different configurations.







Usability

The LETT analysis shows that many students struggled with the basic tightening of bolts and nuts. Even though students have to learn how to do this, this is not the aim for this concept. Therefore this is simplified by making it possible to hand tighten the nuts with this 3D printed modification. In the future this can be off/the self parts.

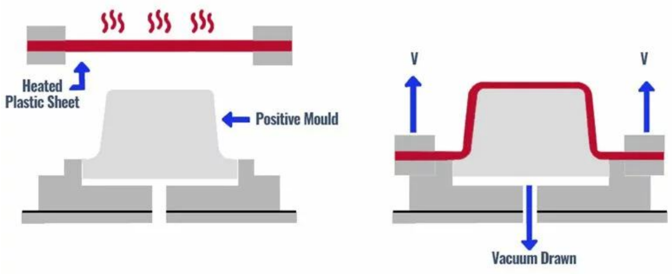
Production and cost

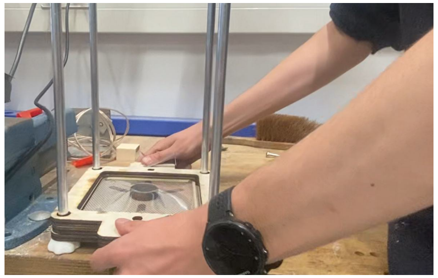
The production process for this prototype involves only laser cutting and sawing, resulting in low costs and ease of repair.

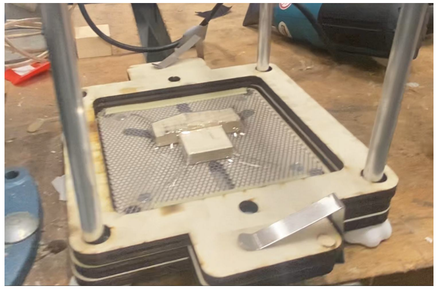
2. Vacuum forming configuration

Vacuum forming in a nutshell

A manufacturing process where a plastic sheet is heated up to the point that is becomes elastic. It is then pulled/draped over a mould. Lastly the air between the mould and the plastic sheet is removed (vacuum suction) which allows it to form tightly to the shape of the mould. When the plastic is cooled down the mould is removed and you have a plastic sheet in the shape of the mould. (Vacuum Forming: What Is It and How It Works, 2022)

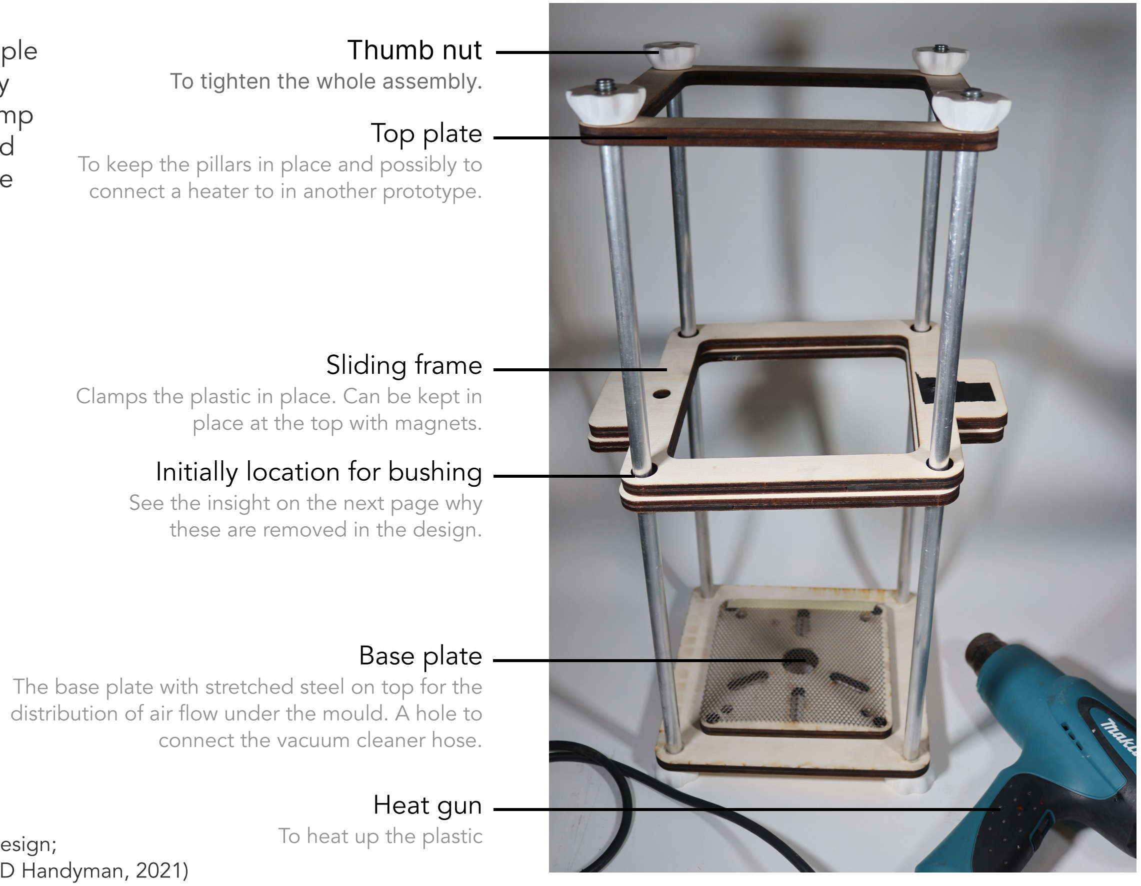






Setup

The vacuum forming configuration was quite simple because forces are relatively low. The hardest was to clamp the plastic well, have a good vacuum seal and to slide the frame down.



References and inspiration for this design;
Detaild CAD vacuum former; (The 3D Handyman, 2021)
Very simple vacuum former; (BrainfooTV, 2017)
Adam Sevage tested; (Adam Savage's Tested, 2021)

Validation

fv-1 Making real products

Validation - The machine proves that designed vacuum formed products can be made with very simple materials, a vacuum cleaner and a heat gun. The design needs more development to make the part better.

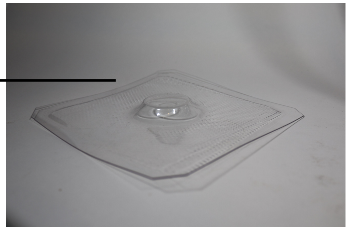
dv- 4 Exciting design

Validation - A feeling of excitement and joy is experienced when making your vacuum formed shape. This feeling is desired when working with the setup.

dv-6 Intriguing design

Validation - When you don't succeed you directly start to wondering why it did not work and want to know what causes it.

What did work well?



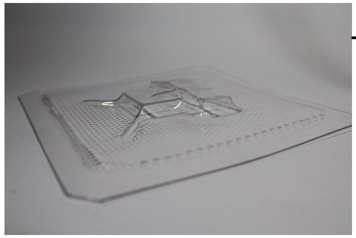
Insights

Insight - Different moulds could be provided to give more insights into the design choices as a designer.

New Requirement - 22. The vacuum former configuration should allow different molds to be used.

What did not work well?

The bushings used to guide the sliding system actually increased friction when the sliding plate was pushed at an angle. Since precise vertical guidance is not crucial, the bushings can be removed. By enlarging the hole diameter, the sliding performance improved while still maintaining the necessary tolerance for accurately positioning the slider over the mold.



Insight - Initially was the idea to use fixed heating with a heating spool. However heating with the heat gun caused significant variations in the result. Making your own designs were leading to a better understanding of the material and how it behaves. What type of elasticity is needed.

New Requirement - 23. The vacuum former configuration should use a manual heating gun.

Insight - The magnets that held up the sliding frame were not strong enough and need modifications.

Insight - The vacuum system was ineffective due to air leaks, which weakened its suction power. Using stretched metal effectively distributed the air and improved vacuum performance. Additionally, vacuuming from the bottom plate proved impractical, as it required positioning the machine between two tables to connect the hose.

New Wish - 30. Connecting the vacuum hose from the bottom does not work, It has to be from the side or top.

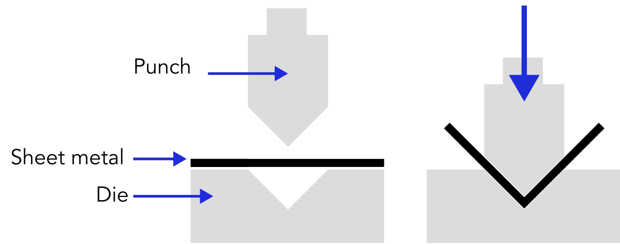
Insight - The setup could be more steady when standing upright and can be less high, and therefore making it more steady.

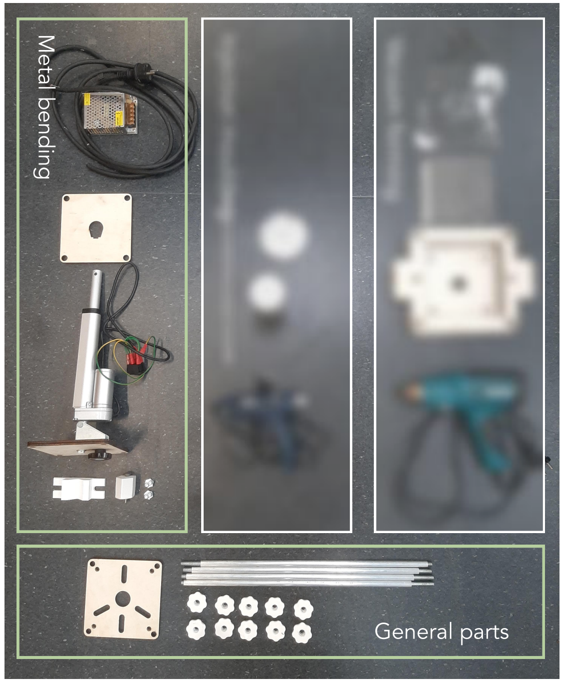
New Wish - 24. The setup should have a robust and sturdy feel.

3. Metal bending configuration

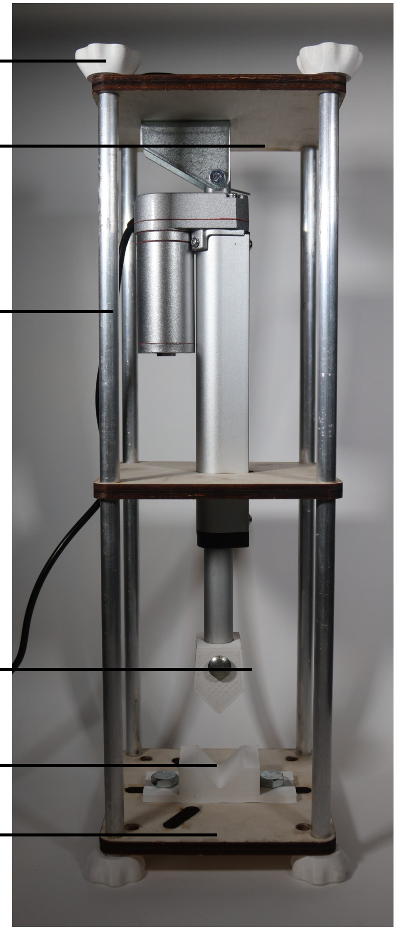
Metal bending in a nutshell

Sheet metal bending is a manufacturing process where a metal sheet is bent to a desired angle using a press brake. The sheet is placed between a punch and a die, and pressure is applied to shape it. The bend angle and radius are determined by the punch and die shapes and the applied pressure. This precise and relatively accessible method is essential in metalworking for creating various forms.





The bending molds do not have to be very over engineered. 3D printed parts is no problem. (Proto G Engineering, 2019; Tyler Bell, 2021)



Thumb nut
To tighten the whole assembly.

Top plate
To keep the pillars in place and mound the press.

Press
Linear actuator (1000N)

Punch
3D printed top mould

Bottom die
With the required bending angle.

Bottom plate
With sloths to connect the mould to

Why this type of press?

One of the most important design decisions in this configuration was to choose the right press type. The 'Plus-minus-interesting' (PMI) method is used to pick the right type. In prototype V3 this is revisited and more research is done into pneumatic pistons/presses.

Pneumatic

Pneumatic piston

+

Switch gear, pressure regulator

+

Compressor + Tank

+ Cheap piston
+ Lot of force
+ Easy to operate
+ Can stop half way

-Expensive compressor
-Many components
-Big components
-Can not easily stop half way.
-compressor makes a lot of sound.
-Hard to manage in a workshop setting, one central compressor?

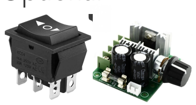
(Nevon Projects, 2022)

Electric

Linear actuator

+

Optional



Switch + PWM

+ Cheap
+ Lot of force
+ Easy to operate
+ Can stop half way
+ Speed can be regulated by PWM

-Force is always 100%, no limiter but an overload protection.

Hydraulic

Car jack

+ Cheap
+ Lot of force

-Too much force
-One way, down is by gravity

Two-way cylinder +

+ Two-way movement
+ Lot of force

-Too much force
-expensive, many different components

Manual

Manual press

+ Cheap

-Feels to little like a real machine/setup
-Requires bigger foot surface than alternatives.

Especially for the simple way of use, and size I chose this option for prototype v1. A manual press is also a good option. However it creates a different feeling. We have to test if this is indeed the case. The Electric press can not be used for all production methods.

Validation

Validation - The machine worked and also proved that mini metal bended products can be formed with this setup.

dv -4 Exciting design

Validation - Seeing the metal or aluminium bend is a special feeling. You wonder what the limitations are and want to put a bigger steel sheet into it (at least as designer, this has to be tested with the real user.)

Validation - 3D print mold worked well and did not show any deformation and its a good production process for a mould.

Validation - 1000N is enough pressing force for now. (it can press steel sheets with a thickness of 2mm over a length of 40mm)

Validation - The PID controller worked to regulate speed.

Insights

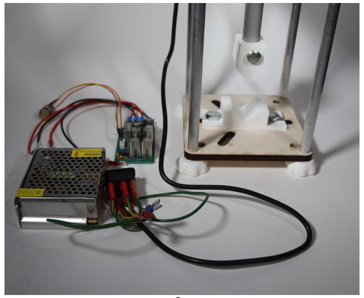
Insight – This doesn't provide deep insights into the actual production process. To truly understand the design requirements, you need to create something tangible and then discover them through hands-on experience.

Est. Requirement - 17. The setup should educate on the Manufacturing methods and materials

New Requirement - 25. The setup should have the same (but smaller) limitations as professional machines to discover design requirements.

Insight - 3D print mold worked well and did not show any deformation.

Insight - The wood is not strong enough for the force (1000N) therefore this has to be reinforced.



Insight - Use different material than wood, cheap feel, students will treat it differently. Currently too 'Do It Yourself' (DIY) feel.

Est. Requirement - 24. The setup should not have a robust feel

dv - 3 User-friendly design

Insight - Assembling all parts takes too much time, to meet the requirement a possible solution is to not have to assemble each part but sub-assemblies.

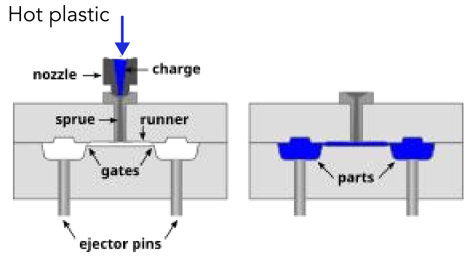
Est. Requirement - 5. The time to setup the setup should be smaller than using the setup.

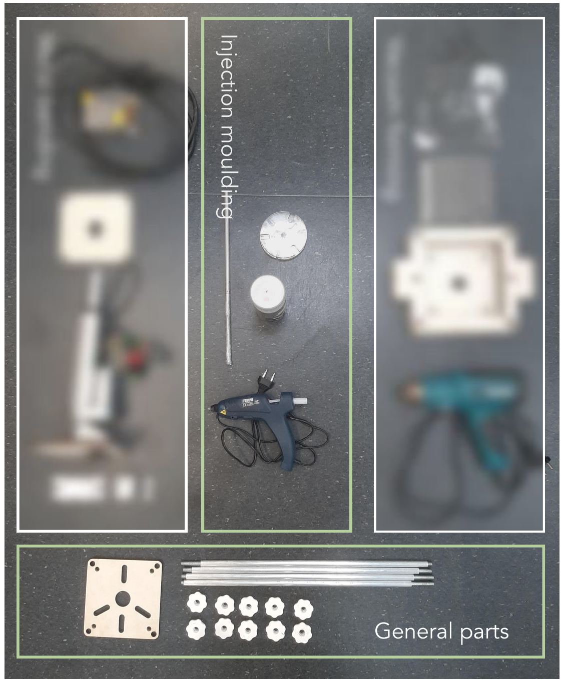
Insight - Currently powered by a battery can be simplified by a simple 12V converter.

4. Plastic injection configuration

Plastic injection in a nutshell

Plastic injection moulding is a manufacturing process where molten plastic is injected into a precisely shaped mould cavity. The mould, which consists of two halves, is clamped together, and molten plastic is forced into the cavity under high pressure. Once the plastic cools and solidifies, the mould is opened, and the finished plastic part is ejected. This method allows for high precision and complex shapes, making it ideal for producing a wide range of plastic components efficiently. (Wikipedia contributors, 2024)





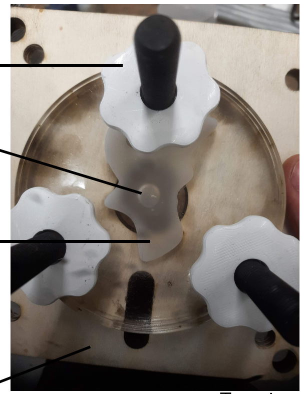
Plastic injection is a complicated process. This prototype version focuses on low-fi prototypes and is therefore super simplified. Inspired by Adithyaa Designs (Instructables, 2022).

The setup makes use of a standard glue gun and glue sticks. These glue sticks should mimic plastic granulate. When the glue is warmed up, the glue gun can be placed on top of the mould. The mould exists out of three laser cutted acrylic sheets. One acting as the bottom of the mould, the middle one has the desired shape and the top one has a small hole. The hot glue is injected via this hole (the sprue).

The setup gave insights into the manufacturing process. However it felt 'too' low-fi, A glue gun is not perceived as new and most people have worked with it. The final product is also a flexible hump of hot glue in a certain shape.

Side view

Glue gun
To inject hot glue (mimicking plastic) into a mould



Thumb nut
To tighten the mould onto eachother

Sprue
The channel that directs the plastic into the mould cavity

Mould cavity
Acrylic mould, so you can see what happens inside. In this picture the cavity is filled with hot glue

Top view

Base plate
The same as in the other configurations. However not really serving a purpose

How to heat up the plastic?



€47,9 (Jaye Heater, n.d.)

€4,79 (Action, n.d.)

€0,89 (AliExpress, n.d.), (Amazon, n.d.)

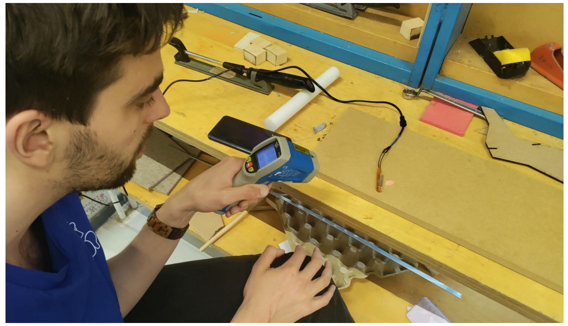
Conventional
The most conventional way to heat plastic in an injector is to use a Solid State relay + Ceramic band heater + PID controller. Since this is a proven method we can assume that it will work. However, to create something that is more Low-Fi, cheap alternatives have to be explored.

Glue gun
It is possible to inject hot glue from a glue gun into a mould. However, it does not feel real enough. The plastic stays warm for long and the glue stays soft. All in all the experience was a bit underwhelming. Therefore I experimented with real plastic (PLA). It worked semi but not good enough to extrude into a mould. Even with high power glue guns the capacity and temperature was not high enough. Because it did ooze out of the gun it can be possible if there is more heat capacity. With price decrease of a factor of 10 this option compared to conventional heating is interesting.

PTC
When disassembling a heat gun I discovered that all these machines work with a 'Positive temperature coefficient' (PTC) heating element. These heating elements do not need a complicated temperature controller and are therefore cheap.

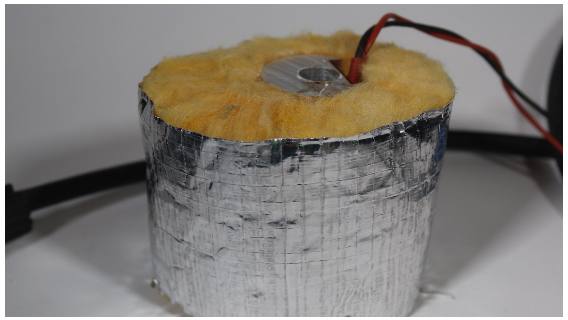
PTC heaters consist
of specialized heating discs built from advanced ceramic materials. These safe, powerful, and energy-efficient heaters allow for exceptional heat production and transfer within even the smallest spaces
(Ltd, 2021)

Desired temp
PLA injection temp >175 ˚C



Ferm glue gun 75W
max temp of the element 140 ˚C
max temp of the chamber 75 ˚C

Stanley glue gun 200W
max temp of the element 150 ˚C
max temp of the chamber 115 ˚C



By wrapping the chamber in insulating rockwool, more heat could be kept and melting went better.

Nothing really is validated in this configuration. It needs more development

Insights

Insight: The initial design did not align well with real-world injection molding machines. To better understand and meet design requirements, it is essential to replicate in small scale the conditions and materials used in actual injection molding processes more closely.

Est. Requirement - 17. The setup should educate on the Manufacturing methods and materials

Est. Requirement - 25. The setup should have the same (but smaller) limitations as professional machines to discover design requirements.

General goal - The goal is to develop all configurations to the level that they can be used to test with the final users.

fv-3 Working prototype (TRL 7-Prototype demonstration in operational environment)

dv-4 Exciting design

Insight - The experience of the machine was underwhelming and not exciting. By making it more real life, with real material this might be more exciting.

Insight - PTC elements are a cheap way to heat plastic to a certain temperature without any temperature regulation needed.

New Requirement 32. - Use a PTC element as heating for education on lowest Bloom level.

Insight - A transparent mould gives a good overview, acrylic works well for this and has a higher melting temp than PLA.

Insight - The total setup will get quite significant bigger if the plastic pressing from a glue gun will be done with the electric press.

Insight - The bottom nuts are very awkward to tighten, you need to flip the whole assembly on its side.

Insight - 3D printing is a good and accessible production methods for these experiential machines.

Insight - When using premium materials, students perception of the value will change, currently too low quality materials, wood, glue gun etc. are used.

Insight - Using premium materials will increase durability and strength.

New Wish - 26. Use premium materials

5. Designer Reflection V1

Since the design is not ready for tests with the end-user I asked myself reflecting questions about design choices.

1. Why is the setup modular and do students have to assemble it themselves?

Requirement 2 emphasizes the need for students to be actively involved in using the setup. By assembling the machine themselves, students engage with every part, which is crucial to the learning process. Consider this analogy: as a novice, when you first look under the hood of a car, you just see a chaos of tubes and containers. You might know how to check the oil, it's only after you've disassembled parts, repaired or replaced them, and physically interacted with each piece that you begin to truly understand how they work together as a whole. As Daan Kayser aptly put it, "You have to understand every single part and its function to understand how something works" (2024).

It also creates familiarity/similarity between different production methods and how the system and instructions work. For example, when understanding the principle of a press the biggest changes are the types of die's that are used.

Thirdly, If the setup is modular, it can comply to requirement 14 - 'educate on different Bloom levels'. The machine and configurations can be assembled in different types of complexity levels. For example; the cheap, low cost injection machine heating unit can only melt PLA plastic with a PTC heat element. Enough to educate in the big UPE course on the lowest Bloom level and make people understand injection moulding. In the small AP course they dive deeper into this subject and require different heating temperatures. In this case a conventional and more expensive way of heating would be more applicable. Therefor the new requirements can be formed.

New Requirement - 27. The setup should be assembled by the student

New Requirement - 28. The setup should be modular

2. Why this size?

When the machine is minimised the required forces also minimize, improving safety (fv-2). The material costs also goes down and it will be more portable (fv-8 & vv-1).

2. Why design for different manufacturing methods?

There are many productions methods. If the setup will be used in workshop, several productions methods have to be thought in a short time span. However, 'one that can do it all' is not a requirement.

Insight - It does not have to be one machine that can do it all.

3. What is the budget?

The current prototype costs €70. The LETT costs >€700 per piece and the TU has 20 available, compared to the LETT the current price (€70) could be increased with a factor 10. The cheapest injection machine on the market costs €150 if you build it your self and €800 off-the-shelf. The goal is to be as cheap as possible. It is expected that €150 is doable and therefore that is the target. However it is not a requirement but a wish

Est. Requirement - 12. Keep cost low (later on define price minimum)

↓

Refined Wish - 12. Keep cost for one configuration below €150

5. Why not just send the students to the PMB or flexspace?

- The capacity of the PMB is limited.
- Machines require safety instruction.
- Price of materials is mostly more costly for bigger machines due to the minimum needed size. Small scale machines can reduce the cost for 300 students significantly.

Recap V1

This prototype demonstrated that it is feasible to create mini-manufacturing machines that are simple to understand and operate. Even tough the machine was not robust enough for user testing, numerous new requirements and insights were obtained, which can be implemented in the next prototype, V2. Additionally, the list of reasons why this design is desirable has grown. To guide the direction of future development, a clear vision has been formulated.

The goal during V1

"Provide students with an experiential setup to learn the reasons why materials and their manufacturing methods are used."

Not only this, the setup is for industrial designers. They have to make design decisions based on the manufacturing limitations and possibilities.

For the full list of requirements and value characteristics please be referred to appendix B.1

Statements V2

Vision

The overall vision in this part of the process it to create a setup that actively engages students by being intriguing, exciting, versatile, and user-friendly. By utilizing a productive failure and experiential learning approach, this setup will enable students to gain a deeper understanding of production processes. Designed to be cost-effective and easy to maintain, it will be seamlessly integrated across the IDE bachelor's program.

The goal during V2

"Provide students with an experiential setup to learn the reasons why materials and their production processes are used, as well as their limitations and possibilities."

Focus

The focus of this prototype is to create a setup for teaching at various Bloom's Taxonomy levels, especially the higher levels compared to Prototype V1. V2 must demonstrate real-life opportunities and limitations of materials and production processes, and it should be ready for student testing, including basic safety precautions.

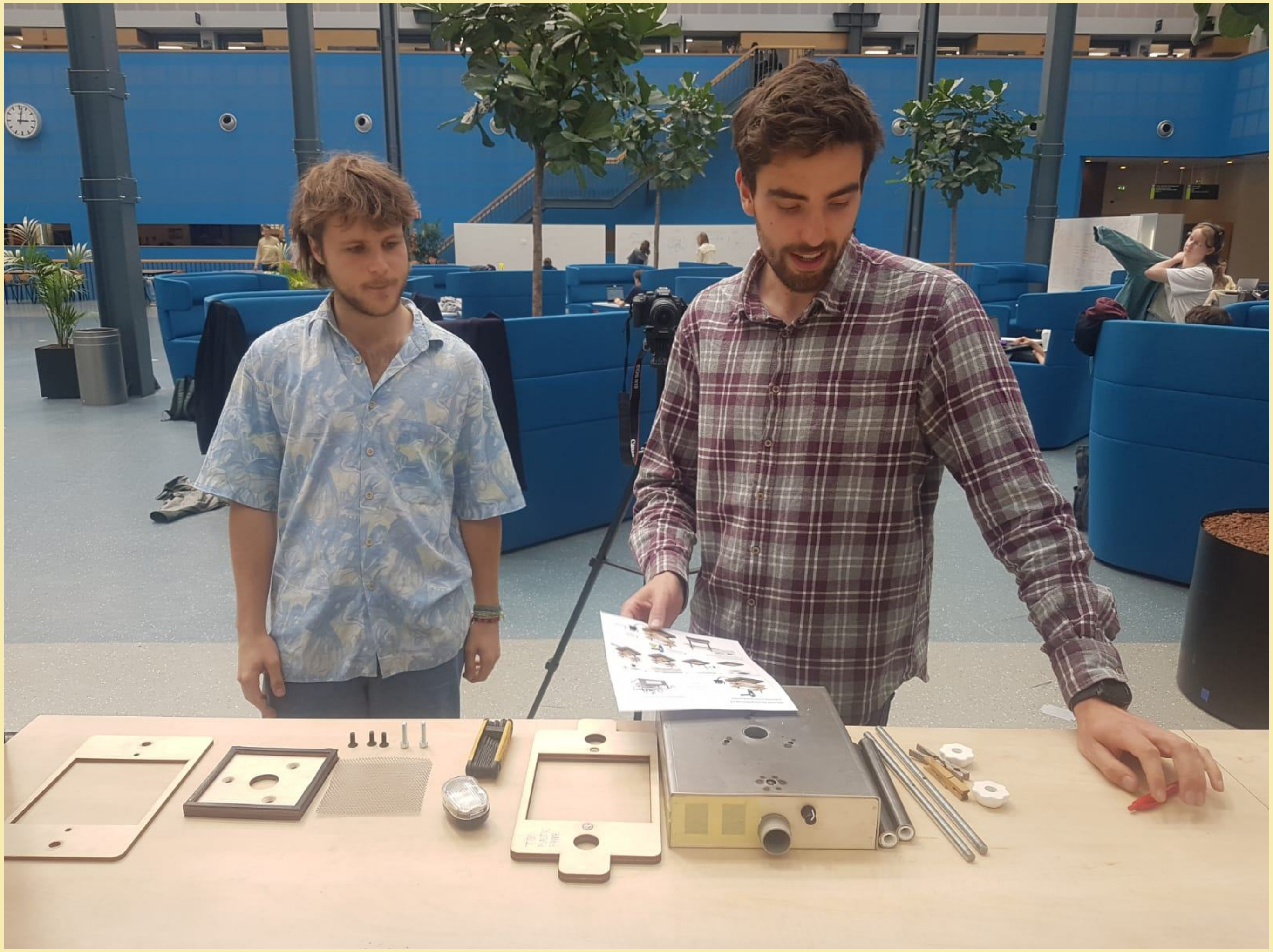
How?

By adding extra functionalities, such as real plastic injection instead of glue from a glue gun. The limitations can be experienced. The press needs to be increased for strength and shape to show real life limitations of industrial machines.

To monitor the performance of the prototype a physical test will be conducted with students. The test will be assessed on its educational value and user-friendliness. To be able to execute this test the first steps towards a workshop have to be developed, such as a manual. Next to that a risk assessment has to be made and submitted to the Human Research Ethics Committee (HREC).

Prototype V2

User testing the design and its early problems

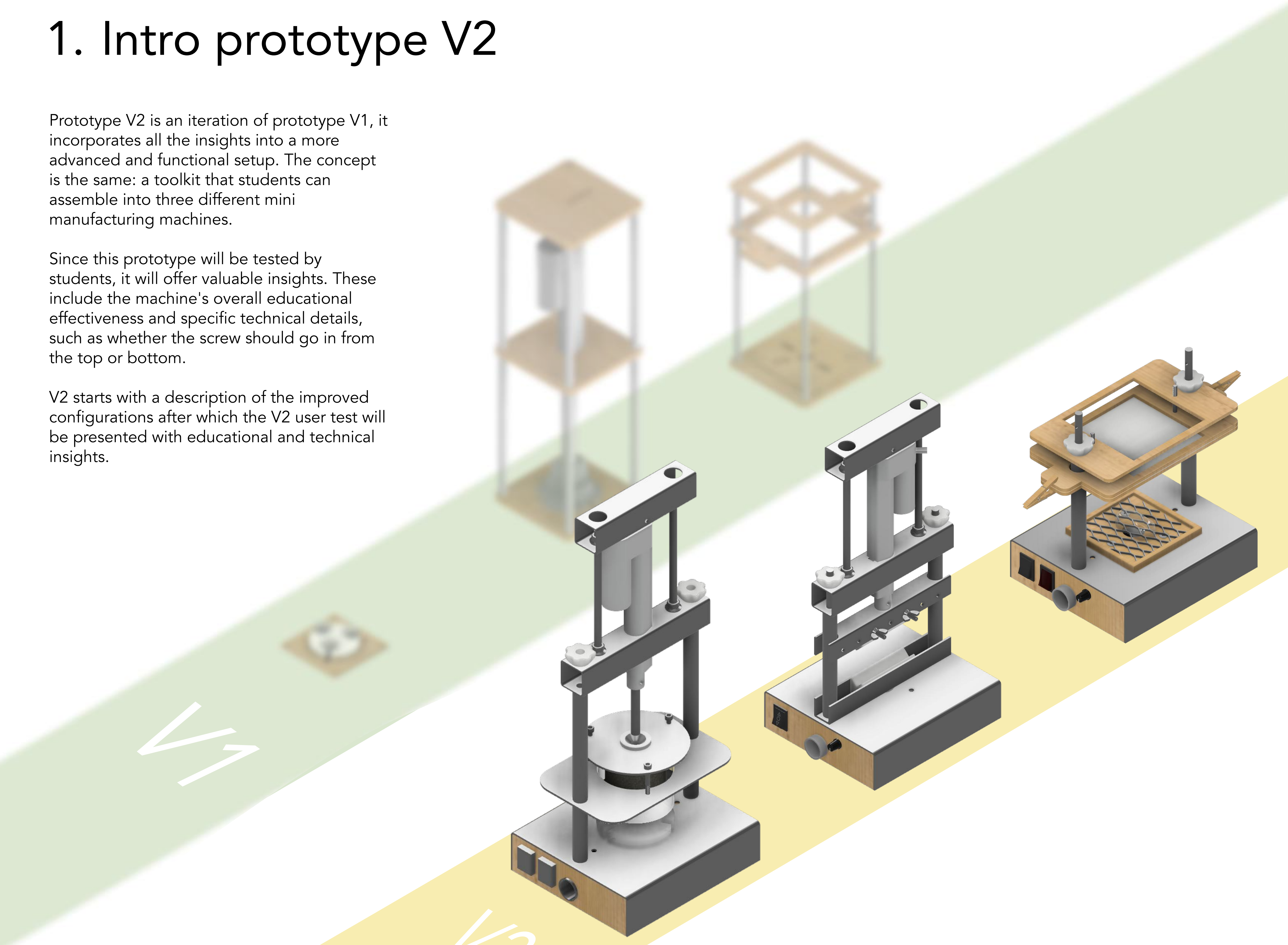


1. Intro prototype V2

Prototype V2 is an iteration of prototype V1, it incorporates all the insights into a more advanced and functional setup. The concept is the same: a toolkit that students can assemble into three different mini manufacturing machines.

Since this prototype will be tested by students, it will offer valuable insights. These include the machine's overall educational effectiveness and specific technical details, such as whether the screw should go in from the top or bottom.

V2 starts with a description of the improved configurations after which the V2 user test will be presented with educational and technical insights.



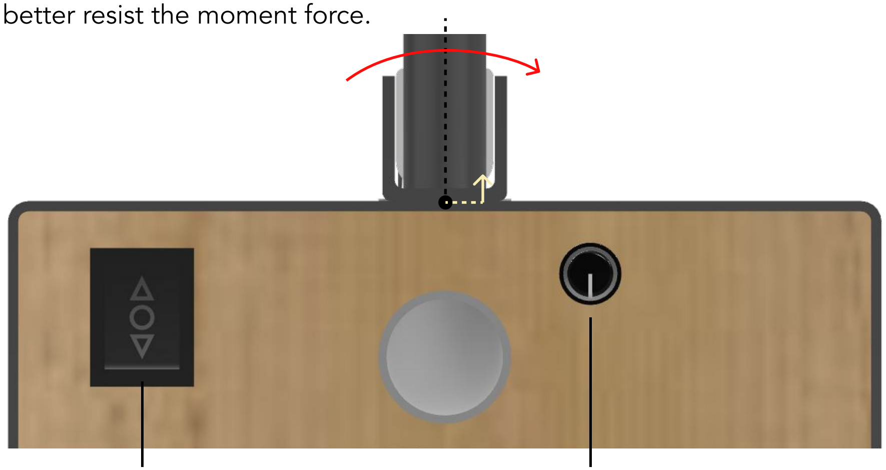
2. Frame design

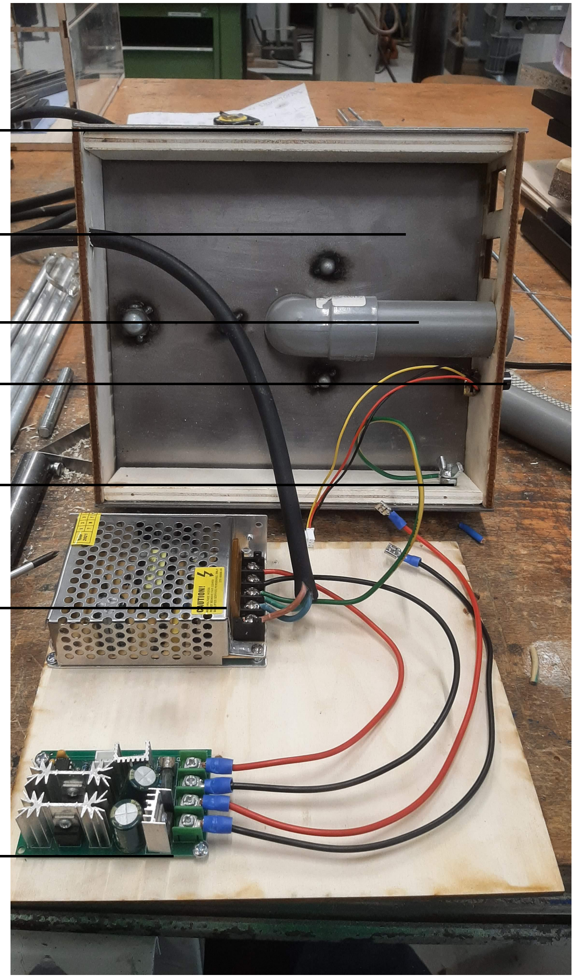
Prototype V1 had many components that could be used in different configurations to suit different production processes. However, this made it unmanageable and chaotic. Therefore, V2 evolved into a single, unified base that supports all production methods while also protecting the electrical component.

Prototype V1 was made of wood but was not strong enough for press production methods. Next to that states wish 24 that the setup should have a robust and sturdy feel. Therefore, this base is made of bent steel. The bent steel not only provides housing for the electrical components but also reinforces the surface being pressed. Through simulations (see appendix B.1), it was decided to use 2.5mm steel.

Prototype V1 had four standing pillars. This was sturdy but also created an over-constrained form. During vacuum forming, the frame got stuck due to the shrinking effect. Therefore, it was decided to use only two pillar to improve user-friendliness and to save on assembly time, part count, and costs.

When using two pillars instead of four, the moment force around the bolting points increases (red arrow). To counteract this, the diameter of the pillars was increased, providing a larger lever arm (yellow line) to better resist the moment force.



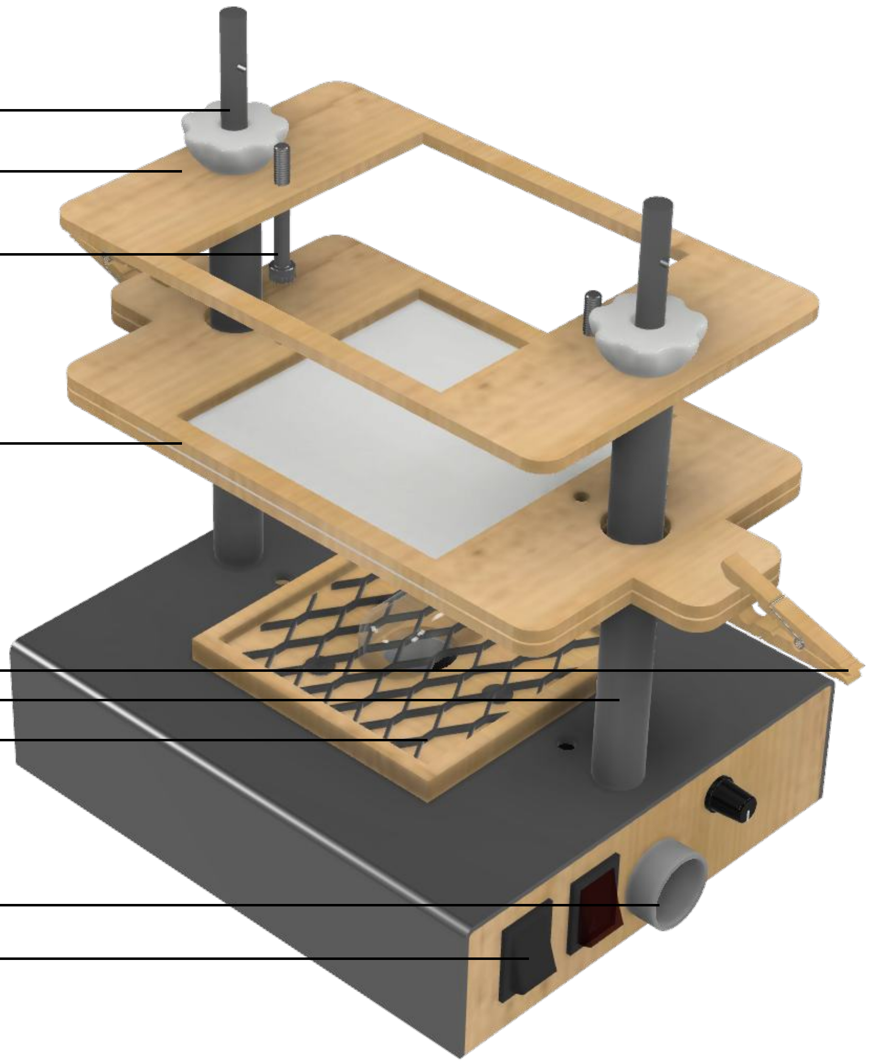


Insight - Technical improvements machine for V3

- The way the bottom and side plate are mounted to the frame are not integrated and the design and therefore improvised. This needs to be done properly, since it takes a lot of manual labour in this prototype.

3. Vacuum forming configuration

The new vacuum forming configuration makes very nice parts. The V2 user test will show that all students manage to make a vacuum formed parts. Requirement 4. states that >80% should be able to use the setup without a manual. In this stage of development peer testing showed that this was not possible yet. Therefore a manual will be used during the V2 user-test. However, the requirement does not change, it is still the aim to meet this requirement in a later stage.



Thumb nut
To tighten the whole assembly.

Top frame
Est. Requirement 23. stated that the vacuum former configuration should use a manual heating gun. However, this was not yet validated and therefore this frame was placed here to potentially become a heating element in the future in case this requirement gets rejected during user testing.
During V2 user testing it becomes clear that heating with a heat gun is indeed much better for educational purposes. Manual heating leads to inconsistent, under or over heating, leading to varying results and allows student to experience how the material behaves when it gets (too hot). Because of this we can confirm requirement 23.

Adjustable bolt
This bolt is placed here to adjust the hight of the slider frame in relation to the top frame. The slider frame is held in place by magnets during heating.

Slider frame
Between this frame, the plastic can be clamped when it is heated and when you slide it down. This clamping force is now reached with clothing pins. To reduce friction with the standing pillar the holes are made oversized.

Clothes pin
These pins clamp the slider frame together and hold the plastic sheet.

Standing pillar

Vacuum bed
This bed is bolted to the base. Via the hole in the middle and the expanded steel raster. air is spread out over the whole bed.

Vacuum pipe
This standard PVC pipe enables the vacuum cleaner hose to be mounted from the side, fulfilling Wish 30, as derived from V1.

Buttons
These buttons do not serve a function in this configuration, resulting in a lot of confusion for the students, as became clear during the V2 user tests.

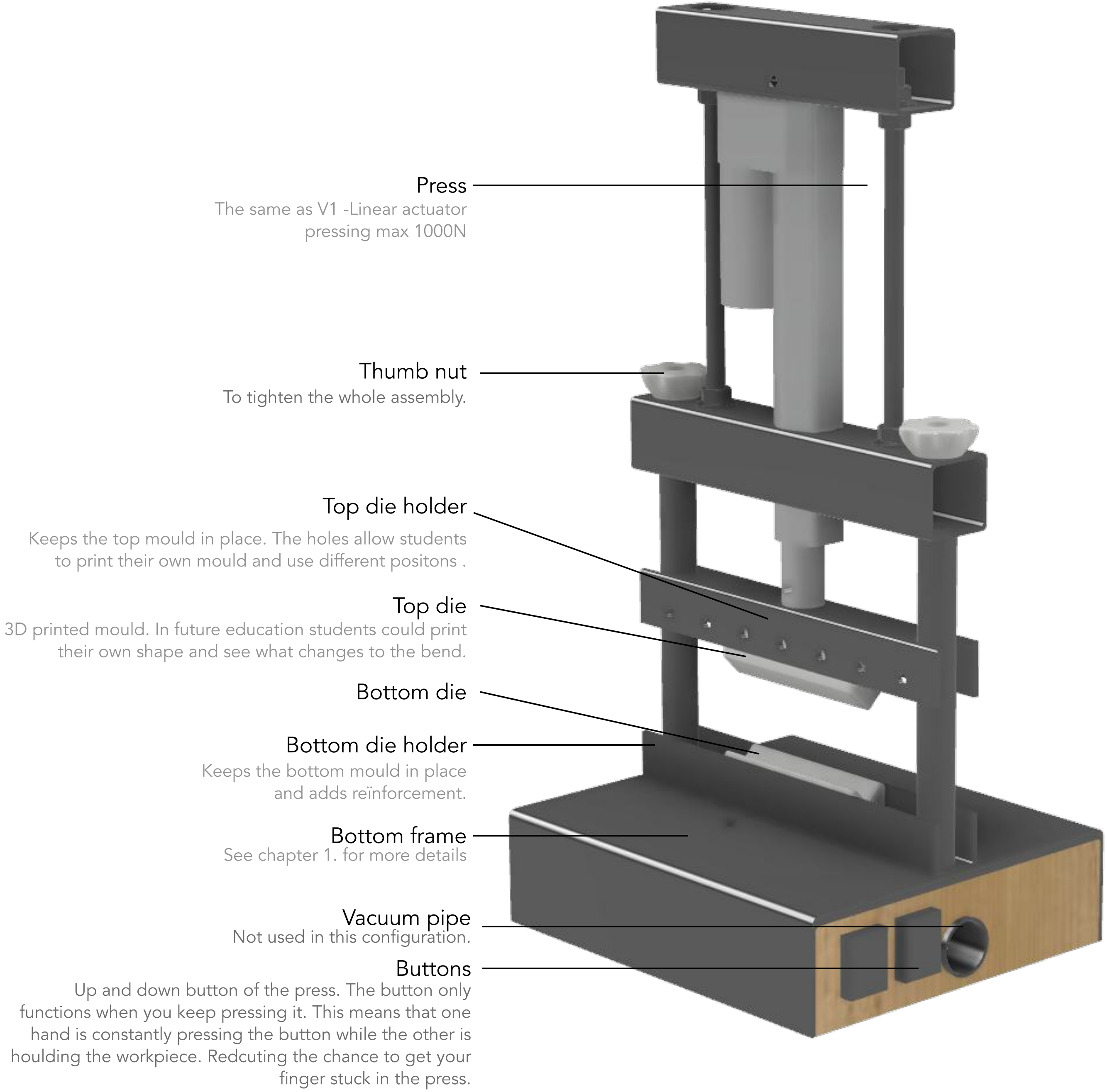
4. Metal bending configuration

The metal bending configuration is similar to V1, with the main differences being increased strength and wider dies, which allow for forming up to 150 mm. The thing about metal bending is that there are many low cost bending machines that can bend big sheets with manual power. The focus of these machines are on education, not on good product results. Therefore it was more important to keep the formfactor and limitations of industrial scale presses. These presses are called press brakes. Additionally, the experience of pressing a button and having the machine perform an action is entirely different from using manual power.

(Amazon.nl, n.d.)

To decide what form factor would be suitable the overview in Appendix B.2 is made.

New Requirement - 29. The setup should be actuated by machine power.



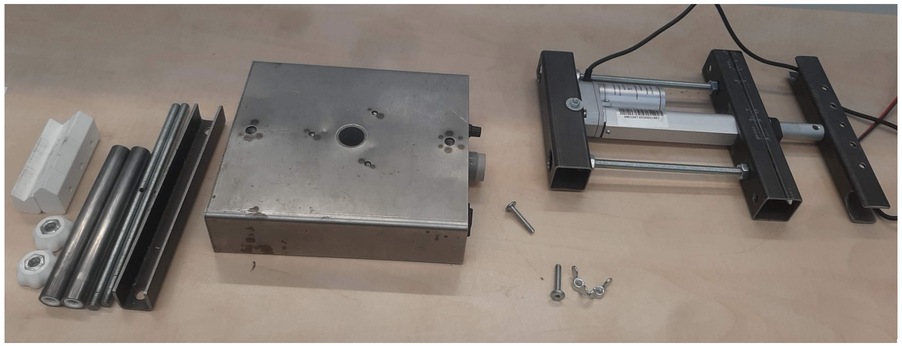
Assembly

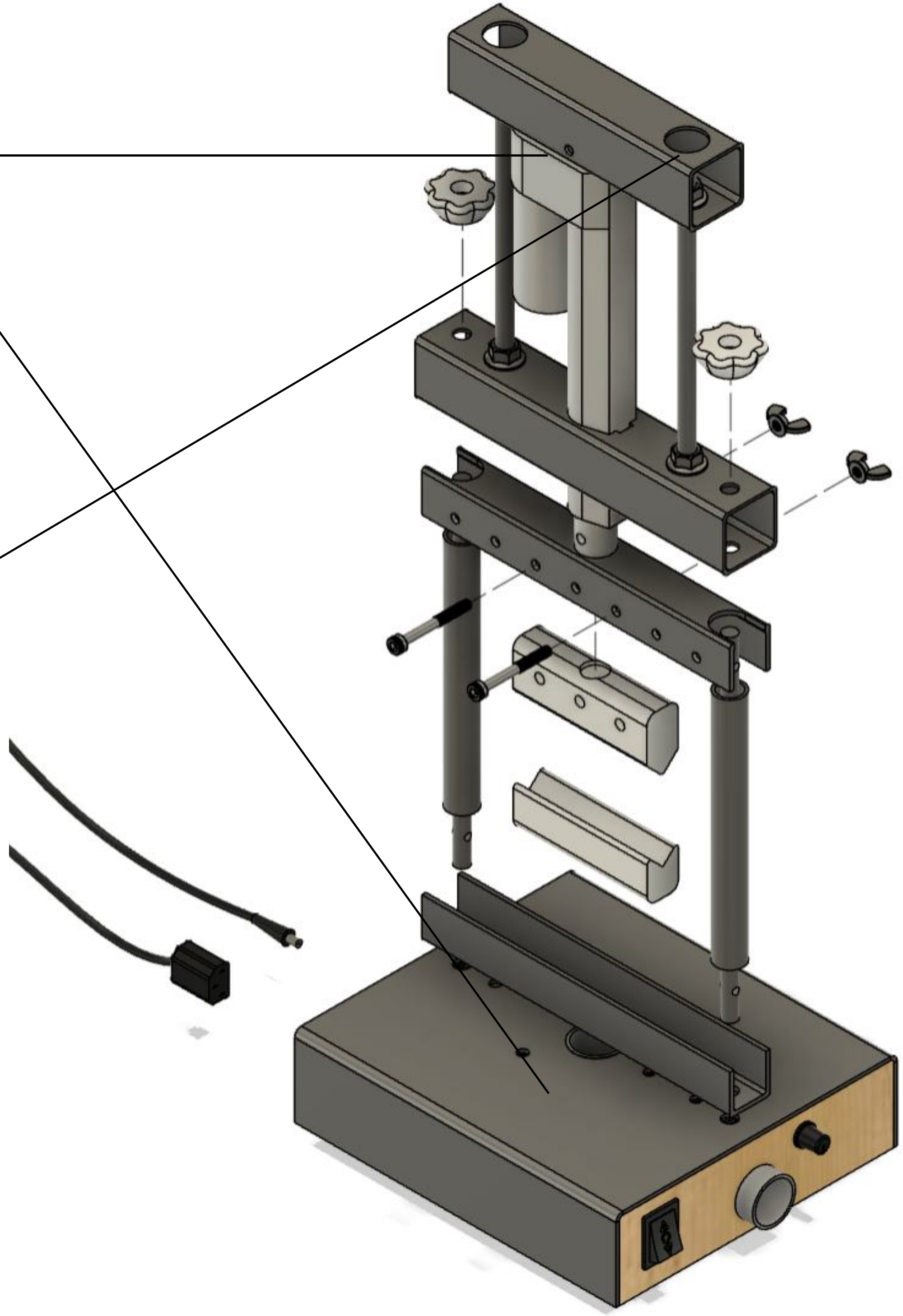
During prototype V1, it quickly became clear that not all parts needed to be detachable. This does not contribute to the learning objective and limits Est. Requirement 5 - The time to setup the setup should be smaller than using the setup. Prototype V1 gave the insight to use sub-assemblies that students do not need to assemble and do not add educational value. Therefore, the linear actuator and its housing, as you can see here, are a single piece. The base plate with all the components too. When something breaks components can easily be replaced if needed.

New Requirement - 31 Use sub-assemblies to keep the focus of student on Learning objectives.

To prevent students from incorrectly (de)assembling the subassemblies, different types of fasteners will be used compared to those provided in the kit. For instance, the press sub-assembly will require spanners to disassemble standard M12 hex nuts, while the toolkit only provides a Phillips head screwdriver and uses thumb screws.

These holes are here to tighten the nuts.





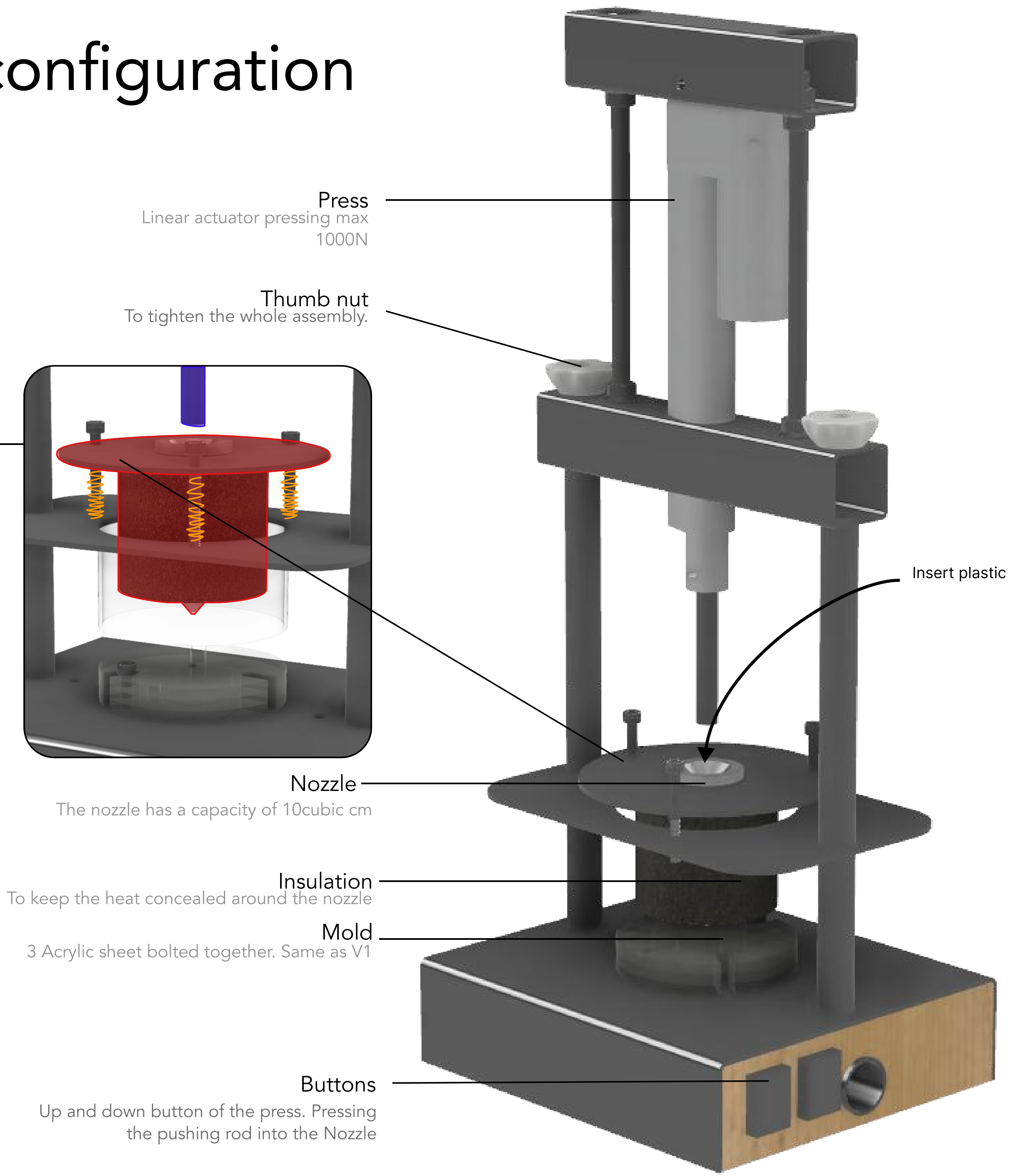
5. Injection molding configuration

V2 got a complete make over compared to V1. Just like the other machines is the educational purpose of this machine the most important. Therefore the heated chamber did not have to be very big to make a educational injection molded part. Next to that is it important to keep the cost low. Therefore a PTC heating element is used (Est. Requirement 32). During prototype V1 the heating decision is explained and researched in more depth.

This mechanism allows the nozzle to have a good connection with the mold when pressing by utilizing the pressing force applied to the molten plastic. The part contoured in red can slide down but are held in the resting position by orange springs.

When the plastic is added into the nozzle (marked with red) and is hot enough to be pressed, the pushing rod (marked in blue) goes down into the nozzle. When the rod touches the plastic, the resistance of the plastic will be higher than that of the assembly marked in red that is held up by springs. This means the red assembly will be pushed down until it contacts the mold. As soon as the resistance increases due to contact with the non-deformable mold, the pushing rod transfers its energy to the molten plastic, that only has one exit which is through the nozzle opening into the mold.

Once the mold is filled, the rod can be retracted, releasing pressure from the mold, making it easy to remove and open.



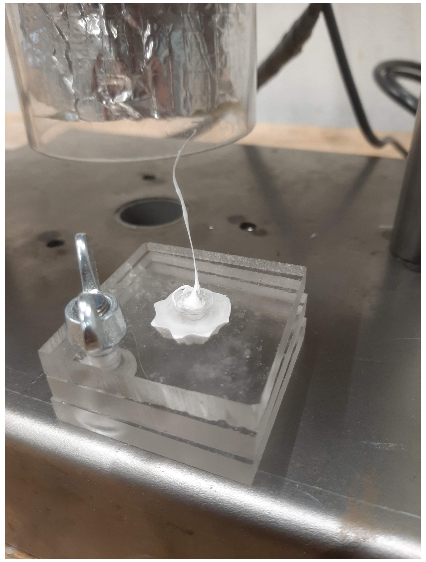
Inspired by the 20g Mini Desktop Vertical Injection Molding Machine available on eBay (eBay, 2024). Currently costing €1500.

The machine does not have a proper way to keep the mold in place. Next to that does it take some time to heat up the plastic and can the machine get very hot due to convection of steel. Therefore it is not user test ready. However a lot of insights were derived from prototype V2.

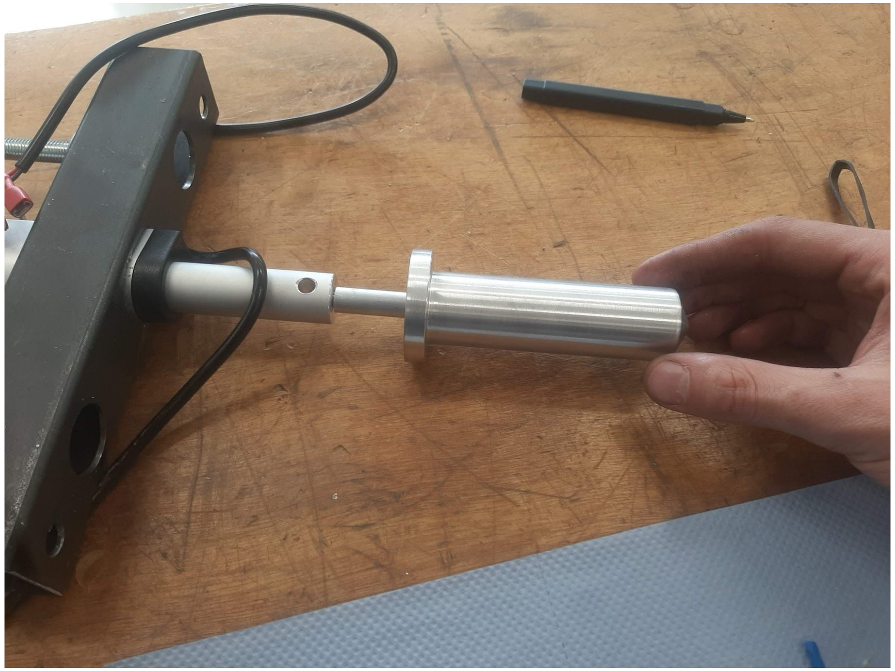
Insight - Technical improvements machine

- Steel frame gets hot due to convection replace for other material.
- Add a holder that hold the mould in place
- A full acrylic mould does not cool down quickly, experiment with one part aluminum. The top can still be acrylic.
- The piston that screws into the linear actuator presses the chunk of Aluminum that is added to the Aluminum from the linear actuator inside. Therefore it is better to use the original mounting hole.

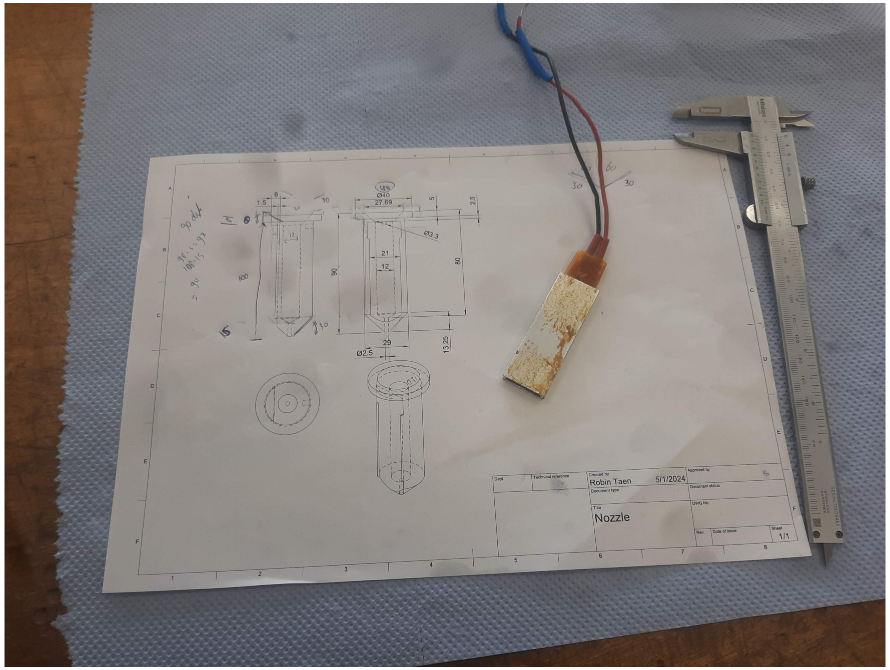
New Wish - 33. The injection molding configuration should have a place holder for molds.



Testing the machine with a V1 mold. Good results!



Test fitting the nozzle and pushing rod. The diameter is chosen to match glue gun cartridges, potentially allowing future iterations to use glue gun glue.



The nozzle manufactured on the lathe, this process takes long and can be very expensive, this has to be optimised in future iterations.

6. User test V2

In this theses, all research involving test with the target group is outlined with a black line and the colour of the chapter. These researches are structured as mini stand alone research papers with their own introduction, method and materials section, results, discussion and limitations.

Evaluating the User-Friendliness and Educational Value of the V2 Experiential Manufacturing Machine

By Robin Taen

Introduction

The main objectives in this stage of the design process is to determine if the experiential setup creates educational value and if it teaches students about manufacturing methods.

Before the setup can create educational value students have to be able to understand and use the setup. That is why user-friendliness is also assessed in this research. These two aspects can be effectively combined, as the user can be observed for user-friendliness while working with the experiential setup and learning about the manufacturing process.

Sub-questions in this research are split in two categories; Educational insights and Technical insights.

Educational;
Do students gain a deeper understanding of the manufacturing process?
Are students engaged while working on the setup?
Are students intrigued and excited?

Technical
User-friendly, Do students understand the machine and what are obstructions?

Testing in the central hal

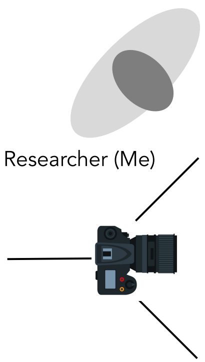
Methods

Structure of the experiment

The participant is asked to make a product part with the V2 Experiential Manufacturing Machine. The part that the participant has to make is a replica that is handed to him/her. All the elements (machine parts) required to make the part are on the table in front of the participant (nothing more to prevent confusion). Before the participant can make the product part, he/she must assemble the machine him/herself. Earlier peer testing showed that this was not possible without a manual. Therefore, a mini manual is provided (even though the requirement is to eventually leave this out). See the Materials section for details on the manual.

Before the test, the student signs a consent form and completes a very basic questionnaire/test (see Materials section) to access his/her pre-existing knowledge of the manufacturing process. Five single questions about the understanding of the process. We are aware that this might not be the most reliable way to tester deeper concept understanding. It did not fit within the timeframe to conduct a more extensive test. This same questionnaire is administered again after he/she has worked with the experiential setup to determine if his/her understanding has changed.

When participants are using the machine the research is an Indirect Observation. According to the guidelines from Ciesielska et al. (2017) there is no communication from researcher with the participant. The participant will be filmed for an analysis afterwards.



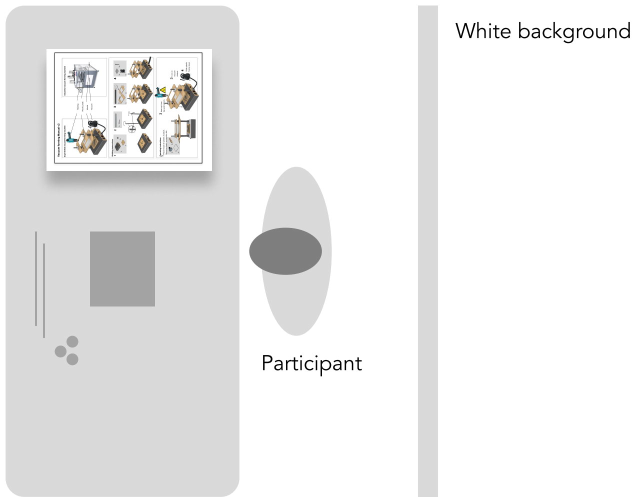
Participants

The test was conducted in the central hall of IDE. Not only because of the good lighting but also to recruit curious participants and to observe how the setup would function in the central hall of IDE. When the first participant started the test more people followed without active recruitment. They were curious what the experiment was about and as researcher, I asked them if they wanted to be the next participant in line.

In total 10 participants executed the test. Of which seven used the vacuum forming configuration, two IDE master's students and five IDE bachelor's students. And three participants conducted the test with the metal bending configuration, all of whom were IDE bachelor's students.

Safety

Because the prototype is not CE certified, a HREC device report has been made. See appendix B.3. In this appendix you can also see all the considerations and design decisions that have been made to make the setup safe.



Video analysis

Video and film is analysed and evaluate using the DEVAN Video Analysis Method. (Vermeeren et al., 2002). The DEVAN method, is a method to analyse user-test video's. It uses time stamps with specific labels that can be used for further development and more overview. In this research it proved to be very practical to pinpoint unique learning moments a (misplaced) use cues.
While analysing the Video's according to the DEVAN method, certain essential markers were missing. The DEVAN methods is designed to analyse how, and if, participants reach the products goal. This experiential machine is not designed to manufacture a part as quick as possible but to educate the participant. Therefore the marker 'education' in short; EDU is added to the list where the participants have an 'aha' moment.
Next to that was maul provided while working with the machine. To trace how much this manual was used the marker READ is also added. This marker indicates when students are reading/looking at the manual.

Sub-questions

Educational;
Do students gain a deeper understanding of the manufacturing process?
- By doing a knowledge test before and after.

Are students engaged while working on the setup?
- This will be assessed by using the video analysis. Engagement is difficult to define operationally, but we know it when we see it, and we know it when it is missing. (Newmann, 1986, p. 242).

Are students intrigued and excited?
- This will also be assessed by using the video analysis

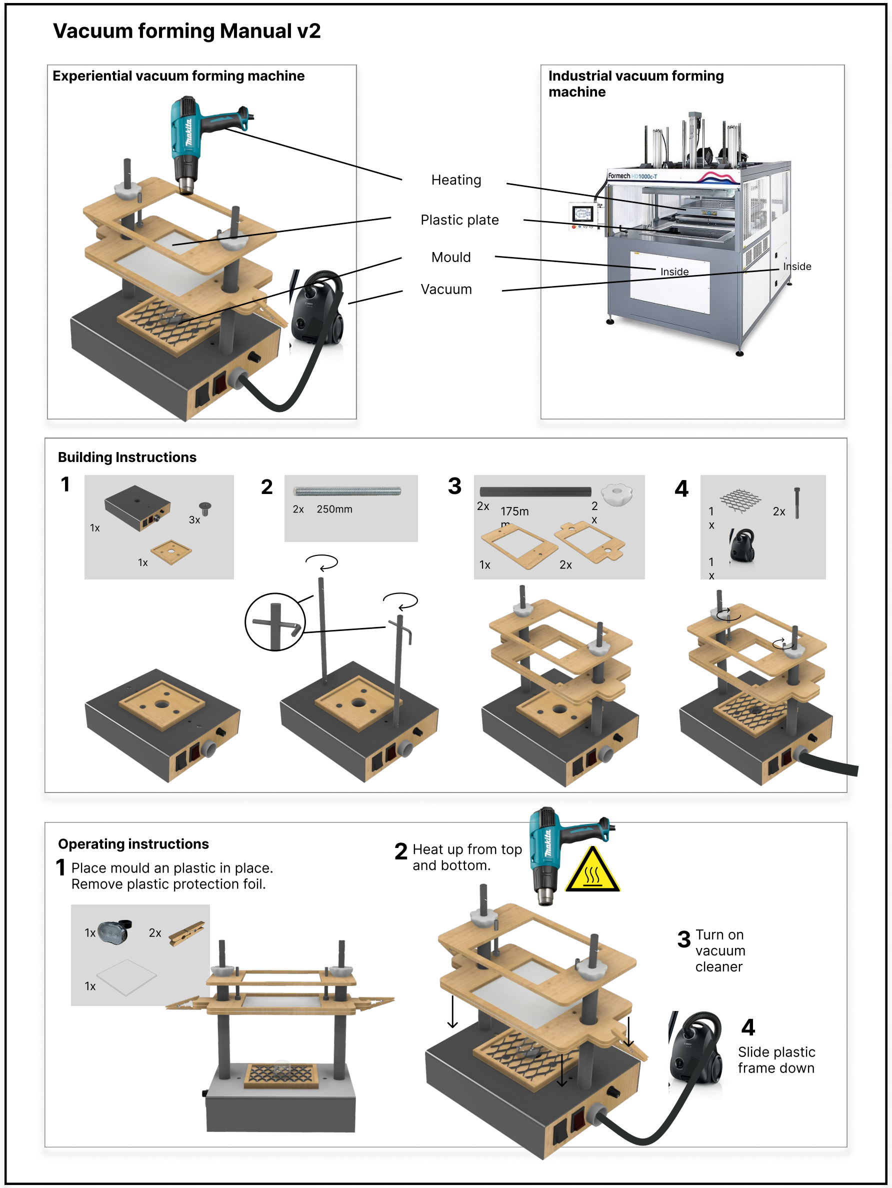
Technical
User-friendly, do students understand the machine and what are obstructions.
- This will also be assessed by using the video analysis

Materials

- The V2 Experiential Manufacturing Machine, see configuration explanations in this chapter (prototype V2)
- Consent form (see appendix B.1)
- Knowledge test (see appendix B.2)
- Manual (see appendix B.4.1 for original & for B.4.2 iteration)

Manual

The Manual V1 initially used a structure similar to LEGO instructions. However, during early vacuum form tests, an exploded view type of manual proved more effective. See Appendix B.4 for the complete manuals. (Building Instructions - Customer Service - LEGO.com US, n.d.)



Results & Discussion

The test results are very positive. In short, the design needs a lot of improvement in technical and educational perspective but the core of the concept seems to work very well. People are super engaged, positive and all walk away with a smile and a deeper understanding of the manufacturing process. The result and discussion section are combined in this mini-paper to get a direct reflection on the results.

Education

- Do students gain a deeper understanding of the manufacturing process?

The overarching goal is to test if students learned something. The short test results were often **not improved after the test**. Especially the question; "Write down three design requirement/factors that a designer should take into account when designing a product for this production process"

We expect that this is due to the higher Bloom level question. With the setup they learned to understand "2th Bloom level" the machine. However they did not analyse (Bloom level 4) or create (Bloom level 6) their own products with the machine. For this, its expected that more time and tries are required. This could be an opportunity for AP and M&M to allow students to create their own products and molds.

Times test performed	Education	Bloom level
≤ 2 **Expected, not validated or tested.**	Understanding the **basics** of the production process.	2 (Understand)
±3 + guided reflection	Understand the **opportunities and limitations** of production **process.**	2 (Understand)
±> 3 + PF workshop	Apply the **design requirements** and behavior of the material.	3 (Apply)

Insight - Students need more time with the machine to educate on higher bloom levels.

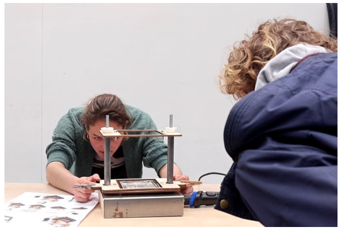
- Are students engaged while working on the setup?

Almost no participant got distracted by external factors while working on the setup. They were very engaged. However, students were often looking in the manual. The 15-35% Of students assembly time was spent with 'staring at the manual'. The manual was described as too vague, most students missed the first step or did not follow it all the way through, forgetting steps or making mistakes. All students managed to fix their mistakes later in the process. With this insight another manual was created, based on an exploded view (appendix B.4). There seemed to be less confusion, however the participant group was too small to know if it made a significant difference)

- Are students intrigued and excited?

As mentioned earlier, the test was conducted in the central hall. The results indicate that in 50% of the tests, someone approached the setup on camera, showing interest and curiosity in the machine.

Several participants stated that they now directly have ideas what they can use the production process for and that the boundary to go into the PMB, and use the big machine is smaller.



Students passing by, pointing to the machine

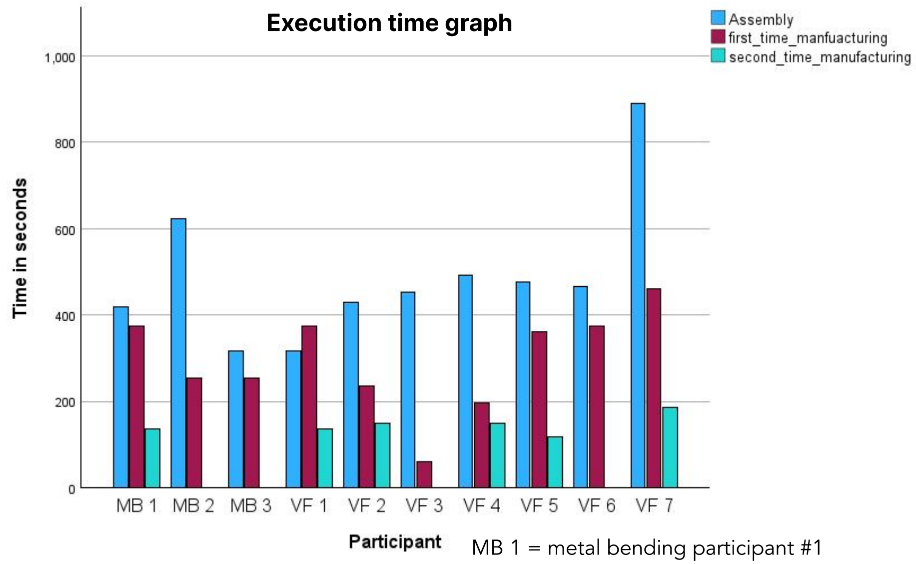
Validation- The machine is intriguing → dv-6 Intriguing design

Technical

- User-friendly, do students understand the machine and what are obstructions?

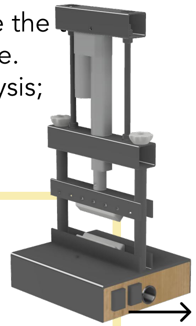
In general we both machines worked very well all student could produce parts. The DEVAN analysis show that assembling the machine takes the students longer than executing the actual test for the first time in both configurations. This has two reasons, the manual is not clear and the assembling is too complicated or takes too much steps. That means that requirement 5. 'The time to setup the setup (this includes assembly) should be smaller than using the setup' is not met and that the design needs to be refined.

Validation- The machine is NOT user-friendly enough.



MB 1 = metal bending participant #1
VF 1 = vacuum forming participant #1

Next to that do we also see that all students manage to execute the faster for the second time, meaning that there is a learning curve. The following technical insights were derived from the test analysis;



Insight - Technical improvements metal bending configuration
- PWM is not perse necessary, also decreases force and sometimes gets stuck.
- Light on machine is instant feedback that it gets power, this functions very well
- The bolt that mounts the top mould are unnecessary, reduce part count.
- Tightening the bolt that connects the top mould holder with the piston from the linear actuator makes the piston twist and possible break, change part.

→ New Wish - 34. Remove redundant parts

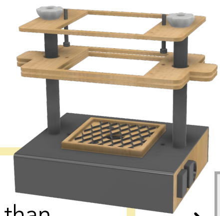
→ New Wish - 36. Connect things to the linear actuator trough the conventional hole.

Insight - Clarity improvements metal bending configuration
- 12V cable did not show that it was connected to machine, draw this line.
- Show sub assemblies that can not be wrong if using exploded view to assemble.

New Wish - 35. Replace bolt connections for snap-fits or mechanical fit

Insight - Technical improvements injection machine
- The machine was not user test ready, improvements discovered by me as designer are stated in the configuration explanation.

→ New Wish - 37. Injection molding is user test ready

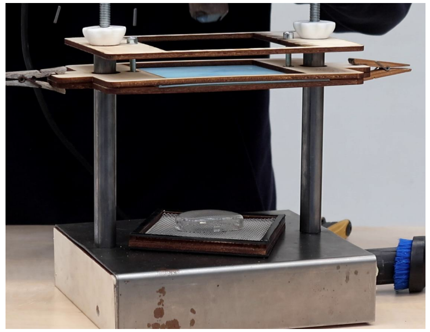


Insight - Technical improvements vacuum forming configuration
- Create a mechanism that holds the slider in an up-position other than magnets since it's overcomplicated and students get confused when assembling it.
- Remove top frame vacuum former. It has no function with the insight that heating will be done manually with a heat-gun.
- Remove clothes pin system to clamp the sliding frame together, clothes pin are not used in the right location and obstruct the sliding mechanism. Clamping force is minimum and adds two loose parts.
- Make it easier to put sheet in the machine and align it in place.
- students do not hold the handles, make these bigger or remove them.
- Bolts on base plate take a lot of time to screw in.
- Make bolt pattern not triangular but remove or make error-proof/poke yoke.
- Currently it's a little awkward to screw in the threated rod with your fingers or with the Hex key. remove it or make it more user friendly.

→ Est. Wish - 35. Replace bolt connections for snap-fits or mechanical fit

→ Est. Wish - 34. Remove redundant parts

By using a circular bolt pattern of 3 bolts the vacuum bed can also be assembled like this....



Insight - Clarity improvements vacuum forming configuration
- Make clear what the function is of each part.
- People wonder what the function is of the rotating knob.
- Adding colours could add more clarity.

→ Est. Wish - 38. Error-proof the design, it can only be assembled in the right way.

→ Est. Wish - 39. The configurations need to be easy distinguishable.

Insight - Manual improvements vacuum forming configuration
- It is too small to see all component
- Add the comment, turn on vacuum former while heating instead of after heating.
- No-one reads the steps in the right order.
- People expect that they already have the first step and not that the first step needs assembling.
- Adding colours could add more clarity.

Limitations

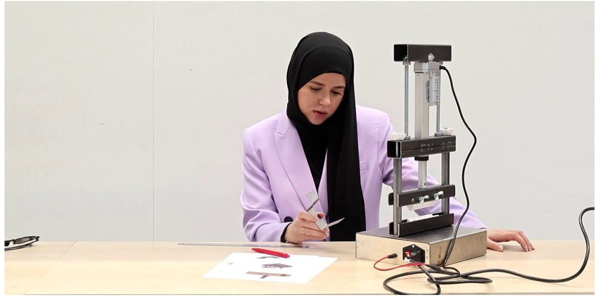
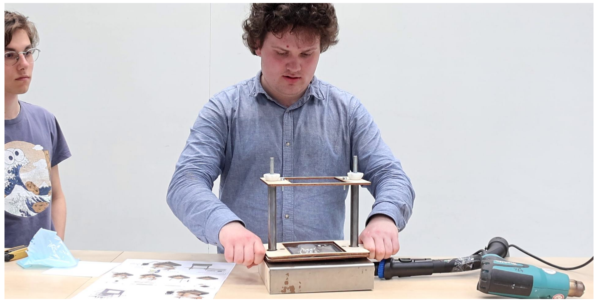
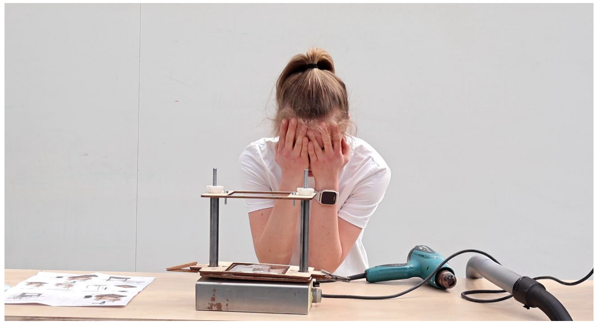
In this part of the project, we can not, and do not want to test the setup on all the criteria. For many criteria its too early to asses. Therefore, things are intentionally left out of scope. For example how the design fits in a workshop context, how versatile the machine is and if its easy to maintain.

In this user test we validate that the machine is intriguing however, this is in a setup where the participant knows its being filmed. In a real life un-supervised context this experience can be very different and therefore need to be tested in a later stage.

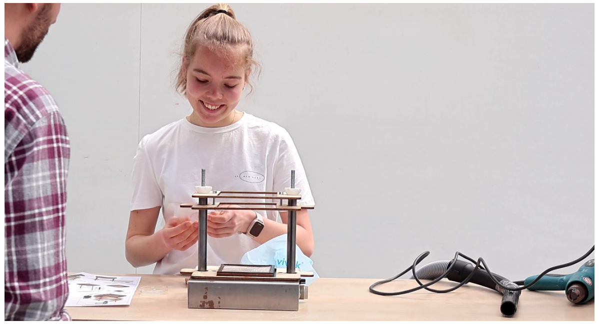
Impression





“I forgot to connect the vacuum cleaner”



“ Try two turned out super nice”

Recap V2

The goal during v2

"Provide students with an experiential setup to learn the reasons why materials and their production processes are used, as well as their limitations and possibilities."

With the results from user test V2 it is important in the next phase to zoom out, how does the setup function in the broader context? How does it change education and how does it fit in? What do the workshops look like? How do all the parts stay in place? During V2 the setup is tested as a standalone educational tool. V3 has to research how the setup function as part of a productive failure workhop.

What are these exact limitations and possibilities? It should be defined and structured in a good overview what the learning objectives are of the machine/configuration.

During testing it became clear how important it was to errorproof the setup. Even with a manual many participants used an trial-and-error approach. This often let to wrong assembly of the machine. This brought me in contact with the Poka-yoke approach. Poka-yoke is a Japanese term, often used in lean manufacturing. It prevents people from making mistakes. It can be as simple as color-coding or as complex as automated systems that stop the process when an error is detected (Shingo, 1986). This way of error-proofing is integrated trough all V3 configurations.

For the full list of requirements and value characteristics please be referred to appendix B.8

Statements V3

The goal during v3

Provide students with an experiential setup that can serve as a standalone educational tool or as part of a productive failure workshop to learn about manufacturing and it's materials, as well as its design requirements, limitations and opportunities. With the goal to improve deeper conceptual understanding and enhance knowledge retention.

How?

By improving user-friendliness from the insights from prototype 2 and using the final materials. Next to that real life workshop material has to be created and tested to see how the machine performs and is thought to students.

What will be tested?

"How do the experiential learning machines, integrated with a productive failure approach, compare to direct instruction and self-guided book learning in terms of educational outcomes within the same time frame?"

Focus

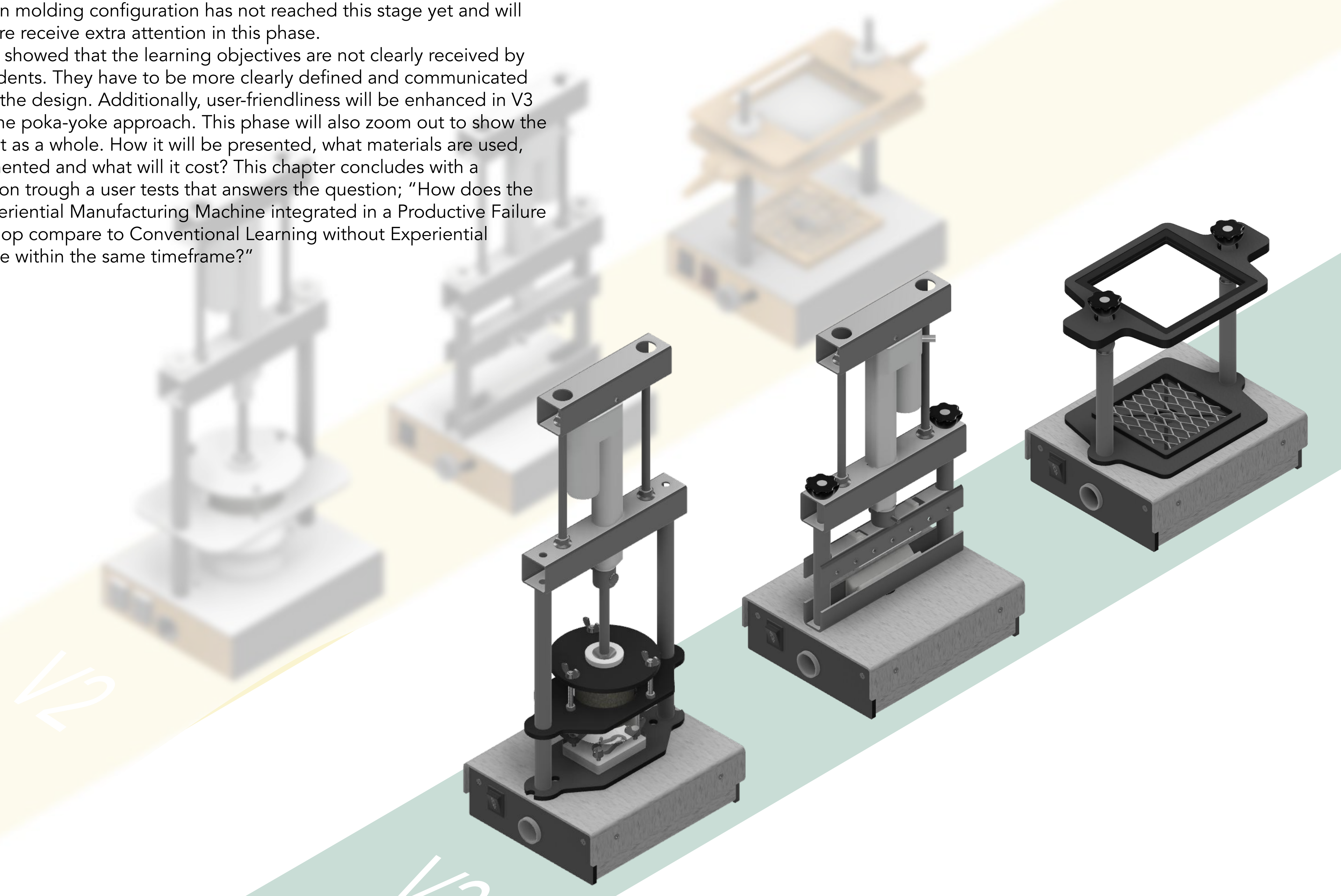
The focus of this prototype is to create a final prototype/model that can be used to test the full design in it's context.

This also means that the prototype (including the injection molding configuration) has to be student test ready. Including the basic safety precautions.

Prototype v3
Validating the design and its context

1. Intro prototype V3

V3 marks the final iteration of this project. V2 showed us that two of the configurations fully function in its context and can make proper parts. The injection molding configuration has not reached this stage yet and will therefore receive extra attention in this phase.
V2 also showed that the learning objectives are not clearly received by the students. They have to be more clearly defined and communicated trough the design. Additionally, user-friendliness will be enhanced in V3 using the poka-yoke approach. This phase will also zoom out to show the concept as a whole. How it will be presented, what materials are used, implemented and what will it cost? This chapter concludes with a validation trough a user tests that answers the question; "How does the V3 Experiential Manufacturing Machine integrated in a Productive Failure Workshop compare to Conventional Learning without Experiential Machine within the same timeframe?"



2. Configuration learning objectives

To gain a better understanding of what we want to learn students while using the setup, the learning objectives are further defined. For IDE students that develop products it is important to know what the design guidelines are for a manufacturing process. Next to that is it important to learn why that manufacturing technique should (or not) be used for the students design, according to its strengths and limitations. The goal is to implement these real-life limitations in V3 and make student experience these learning objectives.

Vacuum forming

Design guidelines
- Mold release - Draft angles
- Avoid sharp corners
- Sheet with one thickness

Strengths
- Low manufacturing costs
- Each individual piece is relatively fast to produce
- Low molding costs (especially when using cost-effective materials like high-density foam)

Limitations
- Only one part or product can be made at a time
- There may be additional costs or resources needed to finish components
- Designs have to be relatively simple, as there's a limit to how much detail you can achieve from a mold

(Engineering Department, Pacific Research Labs, 2020b)

Metal bending

Design guidelines
- Minimum leg length
- Internal radius, standard but can be customized
- Maximum bending length
- Minimum distance from hole to bending line.
- Collision with tools/machine.
- (order of folds)

Strengths
- Can be super strong, cars are made of 0.8mm steel
- No custom tooling/molds needed for most parts
- Low and high-quantities

Limitations
- Product geometry

(Bending Guidelines, n.d.)

Injection molding

Design guidelines
- Wall thickness - Uniform wall thickness to prevent sink or voids.
- Corner design - Constant wall thickness through corners.
- Thickness Transitions
- Ribs - Ribs can improve strength but can create surface imperfections.
- Mold release - Draft angles

Strengths
- Fast production
- Cheap for big quantities
- High complexity parts

Limitations
- High mould cost
- High quantity
- Long starting traject

(icomold, n.d.)

(Used Plastic Car Console Injection Moulding Machine, n.d.)

(LVD Easy-Form Hydraulic press brake)

(Machinetic pro series vacuum former)

3. Appearance

Materials

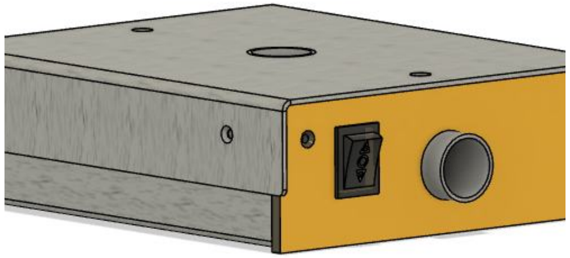
Prototype V2 was made out of steel and wood. This functioned well for the tests that were conducted but did not meet wish 26, 'the setup should be made out of premium materials'. The metal started to corrode (rust) and the wood got dirty and got dents/imperfections. Wood would need a extra manufacturing step where it gets a surface finish such as paint or lacquer. This is not ideal since it adds extra labour to the manufacturing machine resulting in a higher cost price (Requirement 12, keep costs for one configuration under €150). Therefore the wood is replaced by High Pressure Laminate (also know as Trespa). This is much more durable, water proof and already has a colour (does not need painting) (HPL Platen Op Maat Kopen, n.d.). This material can often be found in an educational setting, for example in desks. This is however not possible to laser cut. Therefore this has to be done by a CNC mill. The advantage from CNC milling is that you can design parts that are 3D, making it possible to reduce parts.

With this comes an important consideration. While basic hand tools for wood and steel, as well as laser cutters are widely available, CNC mills are often only available in a professional workshop. This limits the applications where these machines can be built and by who. Education is the primary goal for this project and it is expected that in the context of the TU Delft, the advantages of this material, such as appearance, cost and durability will outweigh this limitation.

To prevent the steel from corroding, many surface treatments are possible, to conventional techniques are powder-coated or using RVS without surface treatment. Chapter '7. Cost price' will dive deeper into the price difference between these two options. For this prototype, RVS resources were not available and within prototyping budget. Therefore steel was chosen for now but can later be replaced with RVS.

Frame design

The frame of prototype V2 was not robust enough on the bottom and required manual labour. This adds a lot of costs in the long run. Therefore the design is tweaked so that it needs minimal manual labour and is very robust. Next to that also aesthetically pleasing. Prototype V2 showed that the PMW speed controller was redundant and only caused extra confusion for the students. Therefore this part left out.



Colour

With the choice to use HPL, an extra painting step can be reduced since HPL already has a colour. The Est. wish - 39, from user test V2 stated that the configurations need to be easy distinguishable. Different colours for the different configurations or parts could add clarity to the design and improve usability. If this will indeed improve usability has to be tested and is out of scope for this project. To reduce prototyping costs only one neutral colour is used in this prototype.

4. Implementation in UPE workshop

As we know does UPE apply a productive failure approach. The structure of this course involves a structured timeline and execution process. The workshops are divided into four phases:

Current workshop structure in UPE course

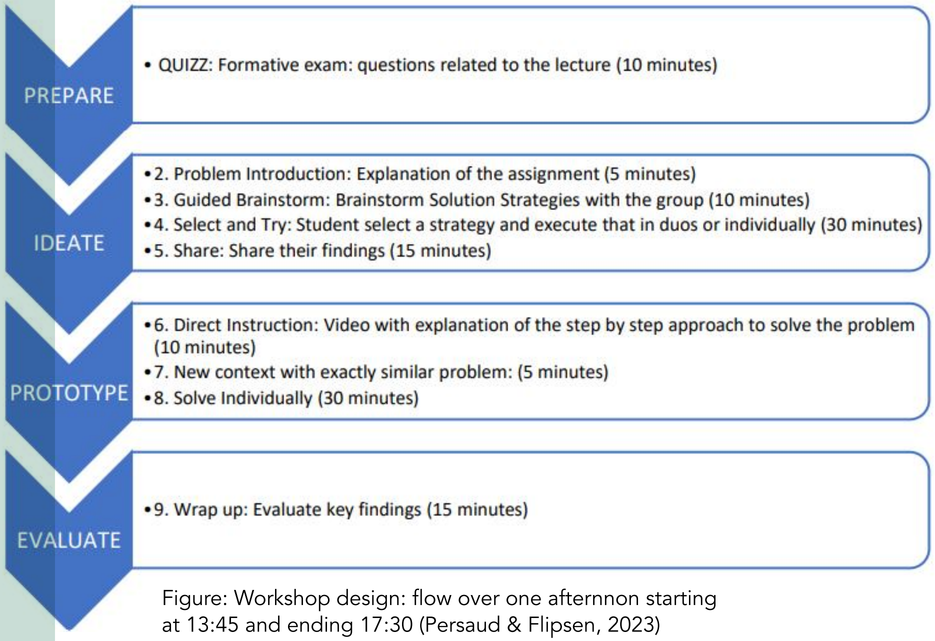
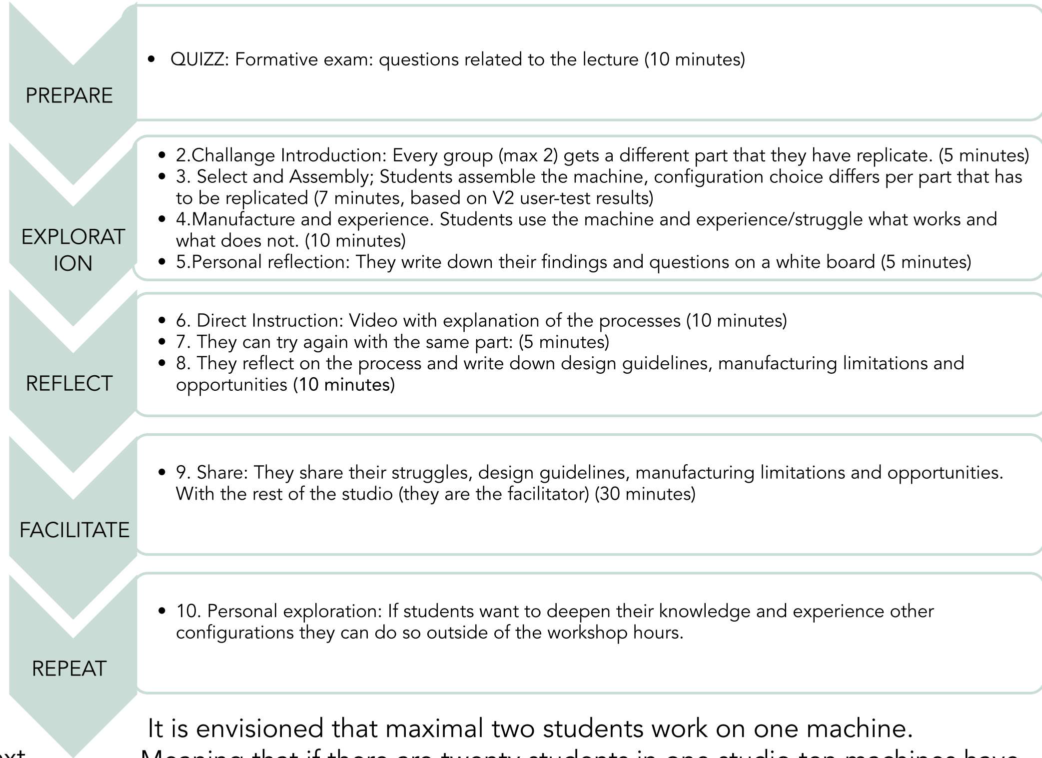


Figure: Workshop design: flow over one afternnon starting at 13:45 and ending 17:30 (Persaud & Flipsen, 2023)

New-proposed/envisioned workshop structure in UPE course with experiential machine.



The current design of the experiential setup can almost directly be implemented within this workshop* due to it's adaptability to its context. The added value is that the experiential setup adds is hands-on learning to the UPE workshop. Since workshop material on manufacturing at this Bloom level does not involve calculations, the structure has been slightly adjusted. Next to that are some labels changed by name and is an extra label added to the list. Because the setup can be used outside of the workshop hours students can explore more if they want.

It is envisioned that maximal two students work on one machine. Meaning that if there are twenty students in one studio ten machines have to be available. In the future all machines might have a different configuration/manufacturing process, but currently there will be more groups working with the same manufacturing process. This diversity is used our advantage during the workshops by making the students the facilitator of the insights.

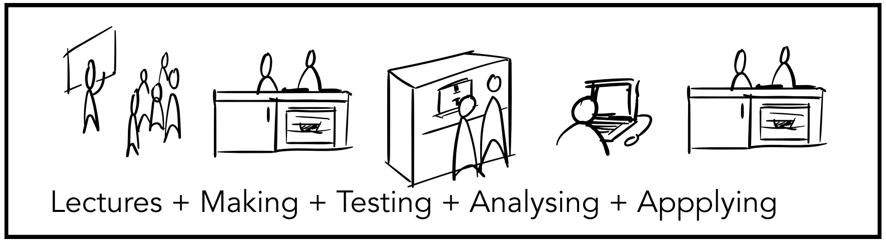
If this way of implementation works has to be tested and refined. It is out of scope for this theses to test this. What will be tested in V3 is how a similar workshop structure compares to Direct Instruction. The reason that this test is different is because it is only tested with one student at the time, not in a studio setting. This is done to reduce variables.

*Note that this only applies for the workshop that teaches about Manufacturing

5. Implementation in M&M and AP

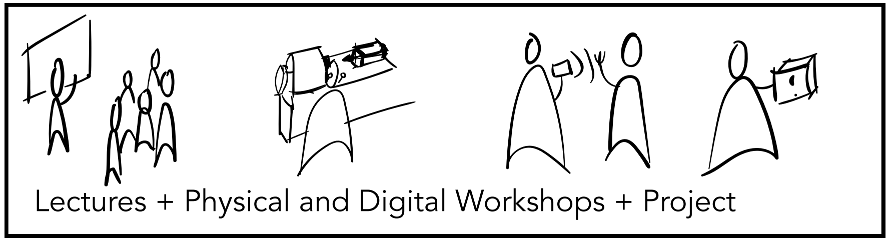
In chapter, Engineering bachelor courses p.18, the structure and course content of M&M and AP is described. Both courses already apply experiential learning in their courses. It is envisioned that the Experiential Manufacturing Machine will fit well within these courses.

M&M course



Currently students test, samples on the LETT tester. With these results they derive the characteristics of their self made bio-based materials. With this they make their final prototype. For example bowls, bags, candle holders etc. It is envisioned that The experiential machine can be off added functionality here. Can they vacuum form their materials or inject it into the mould? Currently the configuration options are limited to three. In the future, when more configurations are developed this can be a nice addition to the course.

AP course



In this course it is all about prototyping and learning about manufacturing processes. Currently a lot of workshops are given in the PMB. This works well and students enjoy using the big machines. However not all production processes are thought. This is where the Experiential Manufacturing Machine can come in and why it was important to educate on different Bloom levels. Take for example the injection moulding configuration (Est. Requirement 14 - To make the setup applicable for other courses it should educate on higher Bloom levels.). The machine does not only educate on the lowest Bloom level; ‘understand’ it also facilitates learning on the highest Bloom level ‘create’. The PMB does not facilitate injection moulding, but it does have milling machines. Students can use their skills learned on the mill to make your own mold. They can then use the mold on the Experiential Manufacturing Machine and create their own part. With this they learn about mold making, the production process and all its implications.

Est. Requirement - 14. To make the setup applicable for other courses it should educate on higher Bloom levels.

→ Validated - The machine can be implemented in different engineering courses and perform on different Bloom levels

→ fv-7 Integration in IDE education

6. Presentation & packaging

IDE is not the first to implement experiential setups; such setups are widely available and come in various formfactors and sizes (Toolkit Technologies, 2024). These can range from toolboxes, bags, and trolleys to display panels and even complete vehicles. The design for this particular setup was developed based on previously established requirements (see requirement below).

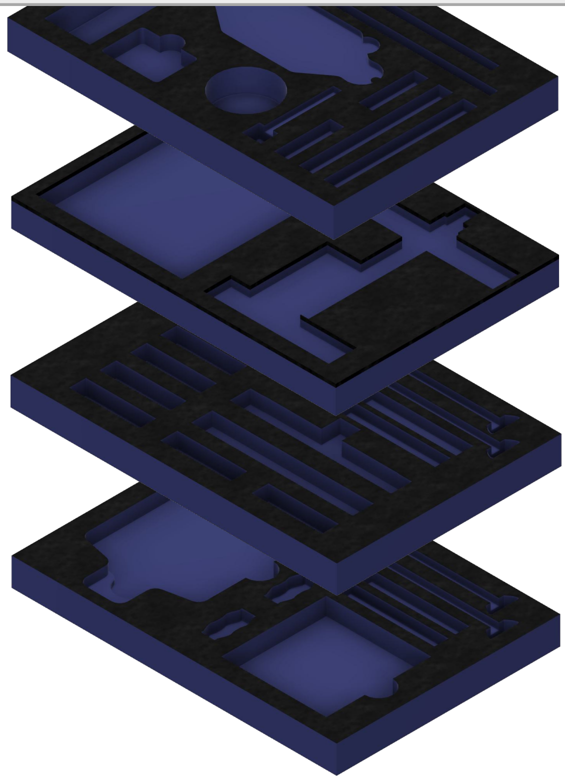
Est.Requirement - 4. >80% should be able to use the setup without a manual.

Est. Requirement - 9. Missing parts have to discovered before using the setup.

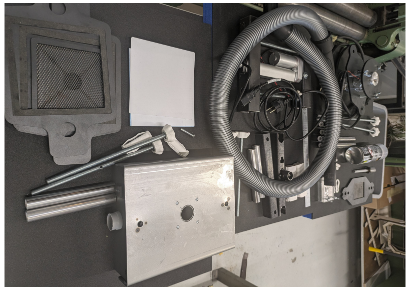
Est. Requirement - 6. The setup should be accessible from all sides.

Est. Requirement - 12. Keep cost for one configuration <€150

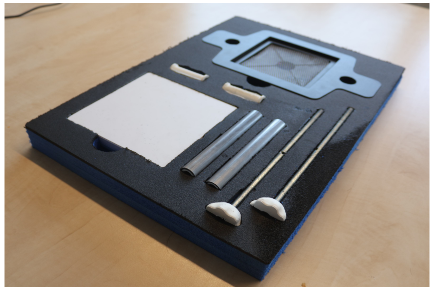
Est. Wish - 8. The setup should be visible in the current daily workday of a student.



Currently, all IDE studios are equipped with four trolleys. Each trolley features a cutting board on top and shelves on the sides, intended for students to store their work. However, these trolleys are often underutilized, as they frequently look like the picture above (messy). This presents a perfect opportunity to implementing experiential machines. To create an organized and efficient workspace, a common technique used is foam inlays, similar to those used in mechanic workshops for storing hand tools.
Est. Requirement 9 states that missing parts have to discovered before using or storing the setup. This prevents students from wasting time on a machine that may not be functional when it's not complete. Next to that can all different configurations be stored separately in their own foam inlay. Making it easier to assemble and meet requirement 4. that >80% of the users can assemble it without manual. These trolleys are mobile, meaning that they can also be used out side of the studio context as a stand alone setup.



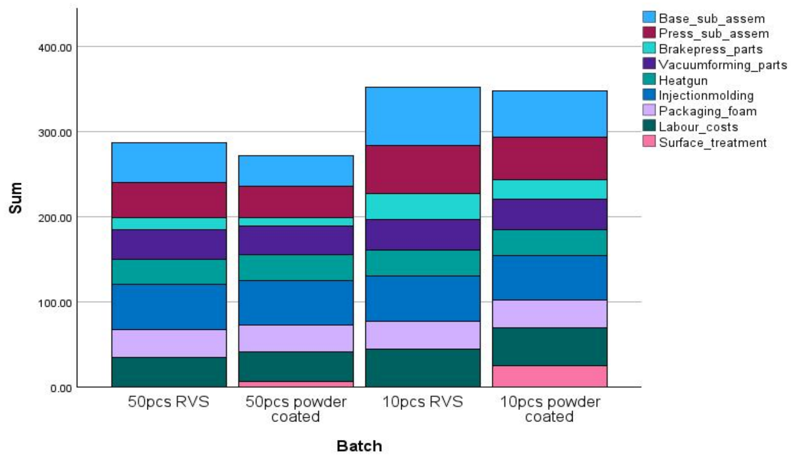
Before, chaos.

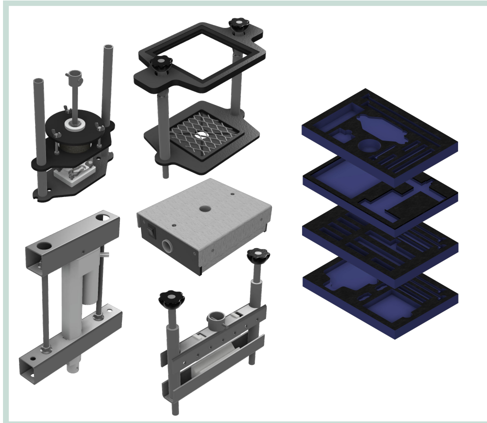


After, structured per configuration

7. Cost price & BOM

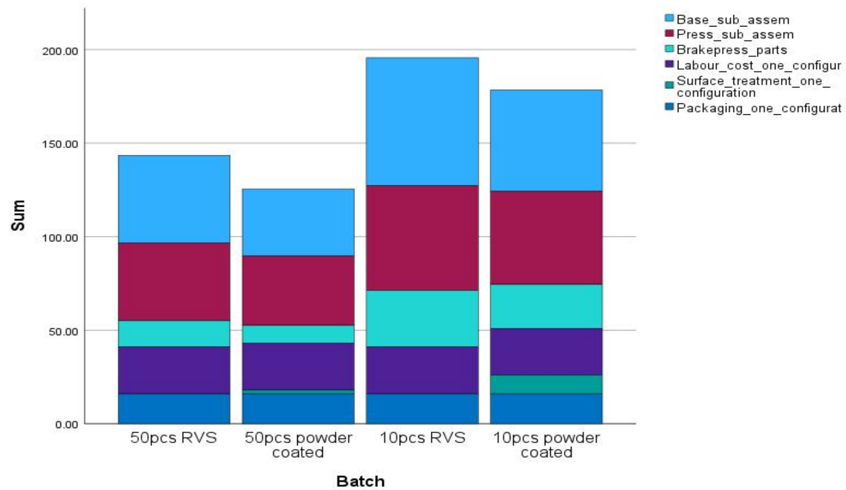
One of the essential factors for this project is to create a design that is affordable. By using many standard components and automated production processes such as milling, laser cutting, and bending, this is achieved. The biggest cost factors are actually related to how the machine is presented and how all the parts are stored in the foam inlays. Next to that is the price depending on the batch size and the metal products, two options are presented; carbon steel with a powder coat or RVS. Depending on the batch size the difference between these choices will differ. Appendix C.1 shows a full overview of all the parts (BOM) and their prices.

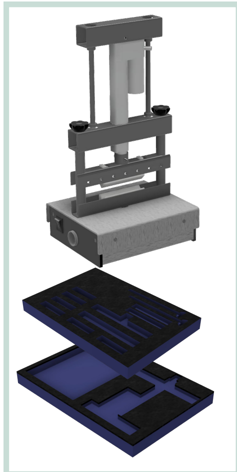




€280 full setup

Total cost price for the machine with 3 configurations. Including labour, heat gun and packaging.





€125 one configuration

Total cost price for the machine with 1 configuration. Including labour and packaging

Est. Wish - 12. Keep cost for one configuration <€150

Validated - The machine with one configurations costs €125, this is under €150 wish 12.

fv-5 Cost estimate is known

vv-1 Low investment costs

8. Vacuum forming configuration

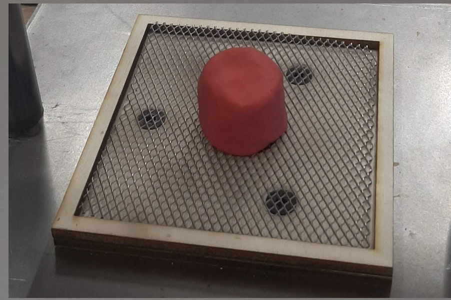
With a fully functioning V2 configuration the functionality of the design remained the same. However many V2 user-test insights and wishes are integrated in the design. By integrating wishes 34, 35 and 38. The total part count is reduced by 50% from 18 to 9 parts and there are no tools required to assemble the machine. This makes the machine much more user friendly, quicker to assemble reduces the cost price.

The mold plays a crucial role in educating students about the manufacturing machine. By using molds with flaws, such as undercuts or sharp corners, students can experience first hand why these shapes are problematic. Initially, clay was used to allow students to design their own molds, but it was too soft and deformed while forming. Basic foam ultimately proved to be the best and most cost-effective solution.

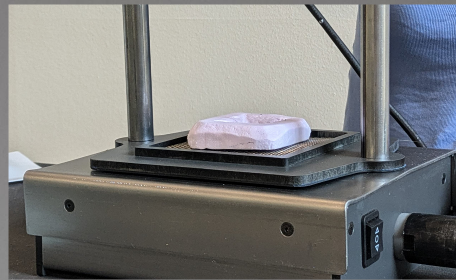
Est. Wish - 35. Replace bolt connections for snap-fits or mechanical fit

Est. Wish - 38. Error-proof the design, it can only be assembled in the right way.

Est. Wish - 34. Remove redundant parts



Clay molds are too soft.



Foam molds work very well

Thumb Bolt

Instead of the earlier versions where you had to screw in the treated rod by hand and used a thumb nut to connect it, this assembly uses a big bolt with a 3D printed head that can be fastened by hand.

Slider frame

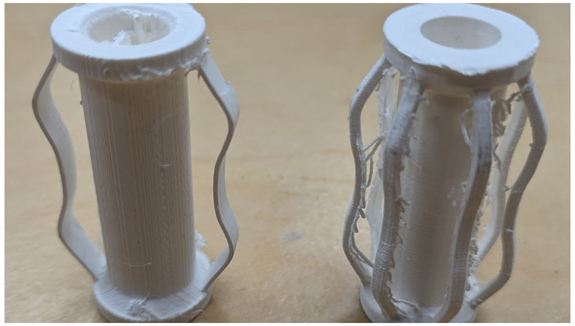
Holds the plastic in place by an engraved groove. The top and bottom frame are keeping the plastic in place by the clamps in the upper position. When sliding it down it is kept in place by squizing it.

Clamps

These snap-fit clamps hold the sliding frame in place. With some gentle pressure the snap fit releases and you can press the slider down. The clips worked very well in the test but over time they deformed a little by the heat of the heatgun. During all the testing the breaking point has not been reached but heat resistant filament would expand the lifecycle of the design.

Vacuum frame

The vacuum frame distributes the air around the mold. Underneeth the frame is a rubber seal that prevents air from escaping.

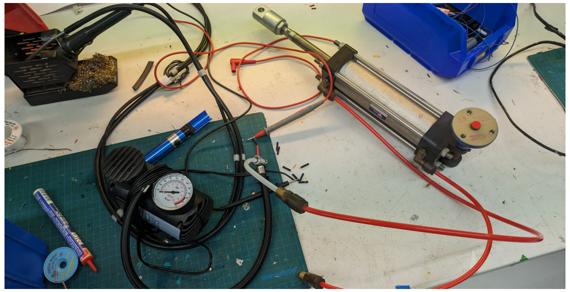


3D printed claps. Printed in different orientations and structures.

9. Metal bending configuration

The metal bending setup is very similar to V2. The main differences are reduced (Wish 34.) parts and easy of assembly. Instead of using bolts to hold the top die in place the die slides in place with little nibs (Wish 35).

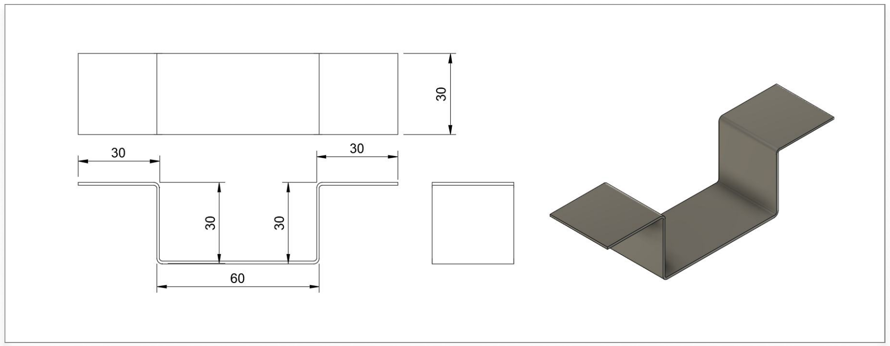
More research is done in press choice (See appendix C.2) Currently an electric linear actuator is used, this functions well but always operates on full force up to a distance. This means that the force can fluctuate and is not constant. Therefore a (simplified version) of a pneumatic cylinder is reconsidered. Appendix C.2 shows a full overview of the alternatives. After all, the initially chosen electric linear actuator turned out to be the best choice.

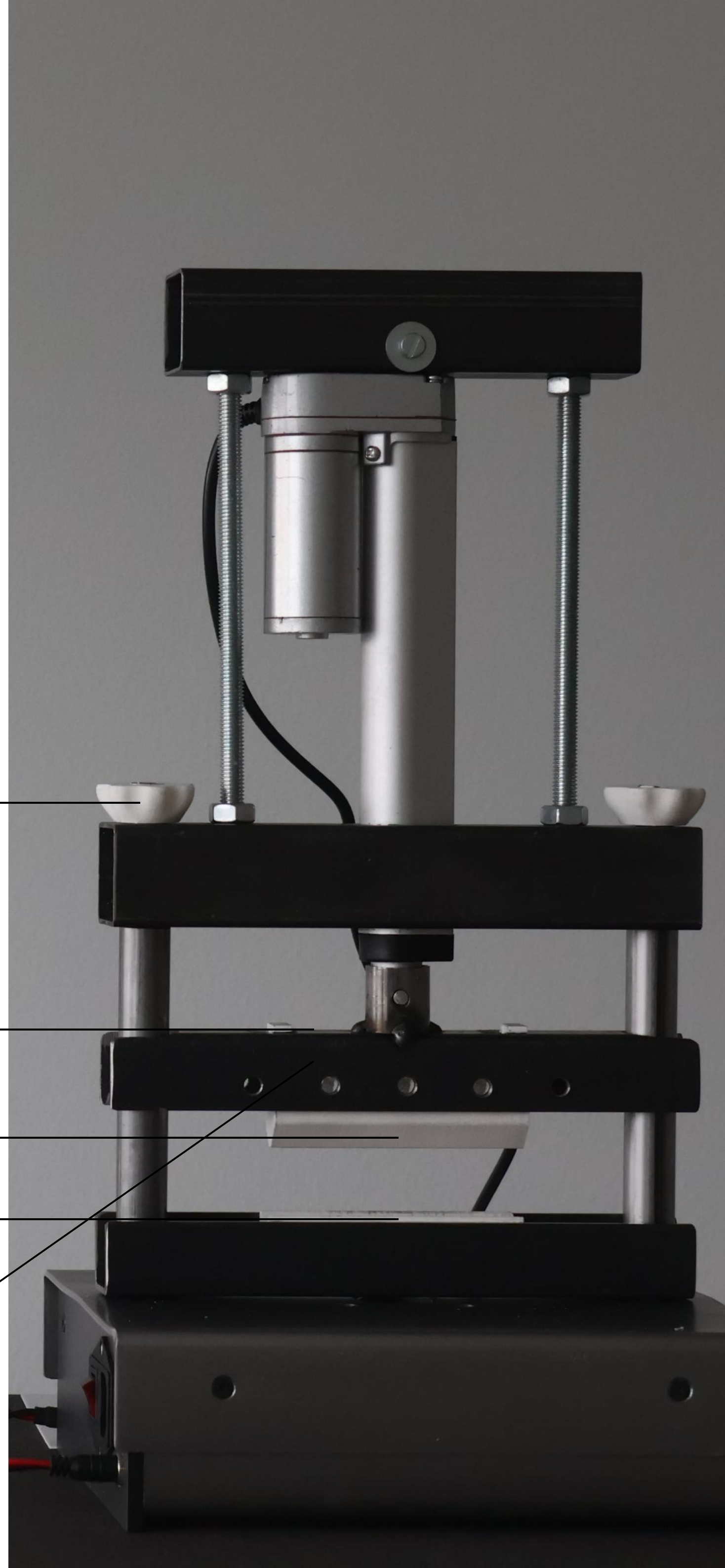


Est. Wish - 35. Replace bolt connections for snap-fits or mechanical fit

Est. Wish - 34. Remove redundant parts

By creating workshop material like (manufacture the drawing) students will experience that metal bending might not be as easy as it looks. Many students fail to get the folding the order right, leading to collision with the machine. The machine is designed to provoke these limitations and to create these learning experiences. More research into workshop material has to be developed.





Thumb Bolt

Instead of the earlier versions where you had to screw in the treated rod by hand and used a thumb nut to connect it, this assembly uses a big bolt with a 3D printed head that can be fastened by hand.

Little nibs

Allowing the molds to slide in place and removing the need for bolts.

Top die

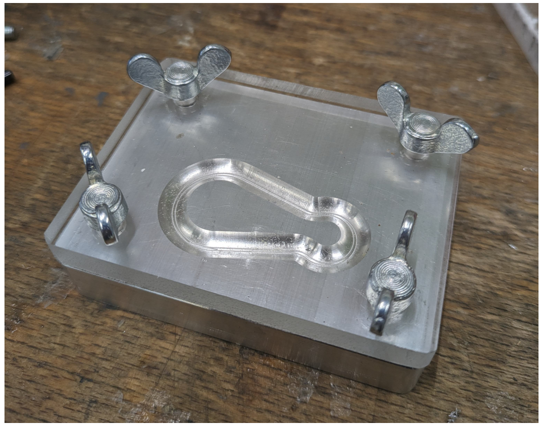
Bottom die

Top die holder

With holes for the old way of mounting the top die.

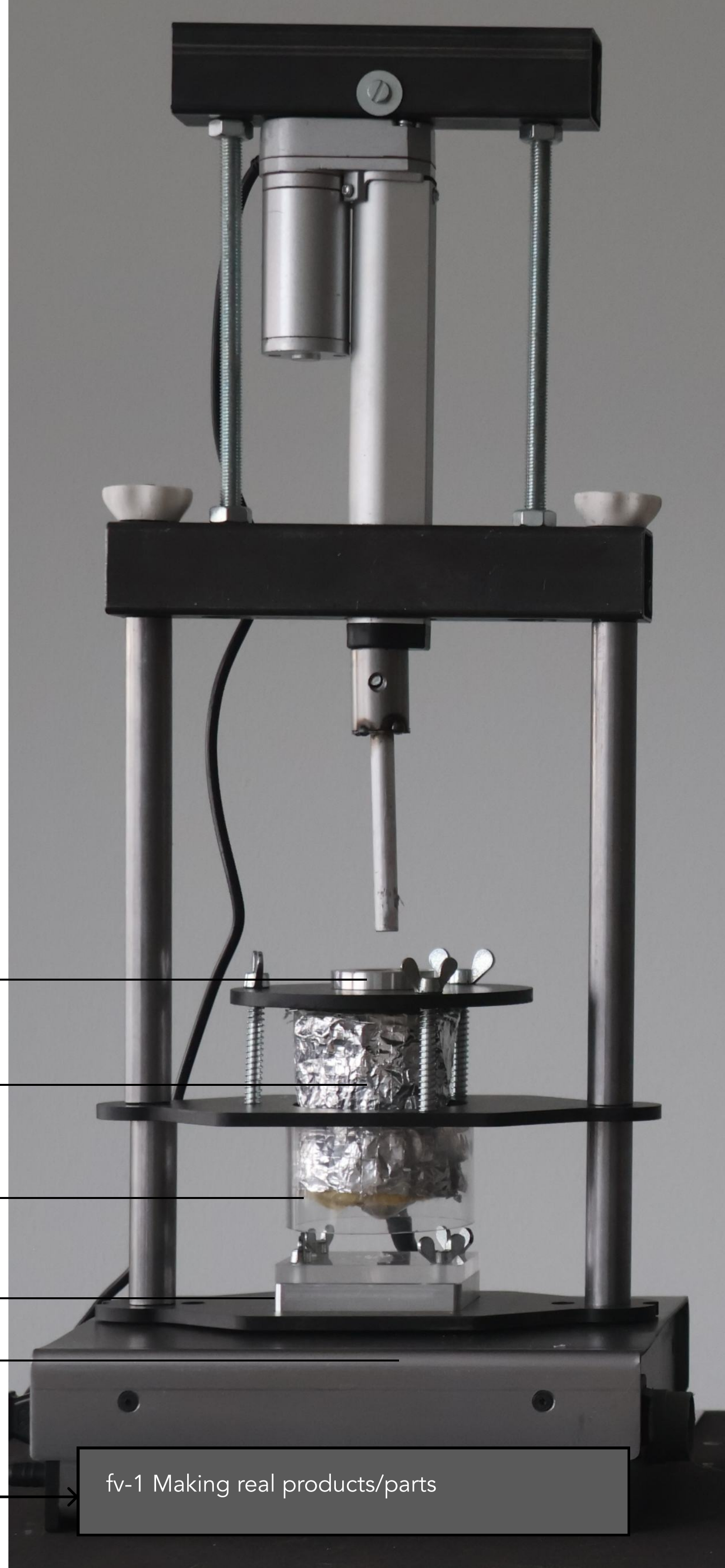
10. Injection Molding configuration

The V3 is the first plastic injection molding configuration that works properly and makes proper parts. The main differences compared to V2 are the materials, the mold and its holder. V2 used steel components to secure the nozzle, but these plates became dangerously hot due to convection. This issue has been resolved in V3 by using HPL sheets, which do not overheat. Additionally, V2 did not have a way to keep the mold in place. V3 has a bottom plate with a secess that holds the mold in place when pressing and allows it for easy removal when changing the mold (Est. Wish 33).



Different materials are researched to make the molds. To allow students to quickly make their own molds 3D printed molds are initially researched. Due to the high temperature of the molten plastic this did not work with standard filament. Alternative options could be epoxy molds or SLA prints with hight-temperature resin. Another option was to make a mold out of aluminium and acrylic. The advantage of this is that the materials are available in the PMB, you can see what is happening in the mold and the plastic cools down quickly. Researching this further was out of scope for this project.

To optimally use the volume of the nozzle and prevent air from getting in the nozzle. Bullets are printed on the 3D printer and placed in the nozzle. Heating of the plastic can take up to 5 minutes, making it sufficient but not ideal.



Nozzle
To keep the heat consealed around the nozzle

Insulation
To keep the heat concealed around the nozzle

Protection
Acrylic cilinder preventing students from touching the nozzle.

Mold
New type of mold

Mold holder

Est. Requiremetn 32. Use a PTC element as heating for education on lowest Bloom level.

Est. Requirement - 21. The prototype makes real products/parts

Validated - All configurations can make parts.

fv-1 Making real products/parts

11. User test V3

How does the V3 Experiential Manufacturing Machine integrated in a Productive Failure Workshop compare to Conventional Learning without Experiential Machine within the same timeframe?

By Robin Taen

Introduction

In order to assess the effectiveness of the V3 Experiential Manufacturing Machine integrated into a Productive Failure Workshop compared to conventional learning methods within the same timeframe, this study was conducted. This study aims to validate whether the design meets the established design brief and contributes to enhancing education. An A/B test is carried out to evaluate the impact of the V3 machine on deeper conceptual understanding and knowledge retention compared to conventional education.

The V2 user test assessed the machine as a standalone educational tool, leading to valuable insights that are incorporated into the development of the V3 version.

The vision of v3 is to actively engage students by being intriguing, exciting, versatile, and user-friendly. Therefore, these factors will also be compared.

Do you feel capable enough to design a product that can be made with the production technique; vacuum forming

Not confident at all	Slightly confident	Somewhat confident	Fairly confident	Completely confident
○	○	○	○	○

Methods

Structure

A/B test is structured in the way to mimic real life situation best. For an structure and task overview see the next page. All participants had 30 minute education about thermoforming. The way how this was thought depended on the group. Group A follows a workshop with a productive failure approach integrated with the designed experiential learning machine. Group B follows the workshop with a direct instruction and self-guided book approach. All participants work independently, limiting influence from fellow students and group dynamics. After this they were asked to participate in a small structured interview that was based on (Likert-scale (Timur & Tasar, 2011)) experience questions.

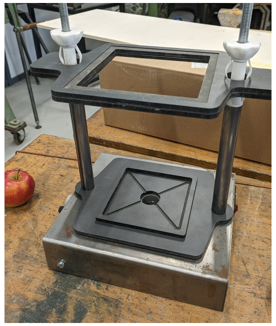
After one week (to test retention) content based questions were conducted in the form of a online questionnaire.

Participants

The study included 18 bachelor students from TU Delft, equally divided between Group A (n=9) and Group B (n=9). Approximately 50% were Industrial Design Engineering students, and the remaining 50% came from various other faculties, with this distribution evenly spread across both groups. The gender distribution was random. Recruitment was conducted through cohort WhatsApp groups and personal connections. With two criteria, not knowing what 'thermoforming' is and a bachelor student. To stimulate serious participation, all participants are asked to complete the questionnaire with their best intentions and focus. To support their participation, they all receive a 20 euro voucher at the end of the research. Informed consent was obtained from all participants prior to the study.

Group A, PF + experiential machine

- **1 min** — Show example of what to make with the setup
- **19 min** — Hands on experience with machine (already assembled)
- **5 min** — Thermoforming explanation video
- **5 min** — Room for questions



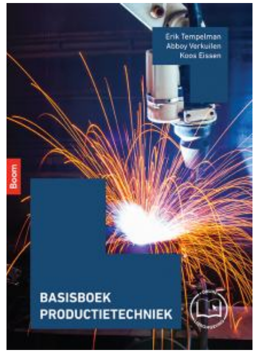
- **15 min** — Experience interview

1 week later

- Questionnaire about thermoforming

Group B, Direct instructions

- **5 min** — Thermoforming explanation video
- **5 min** — Room for questions
- **20 min** — Reading content about thermoforming



- **15 min** — Experience interview

1 week later

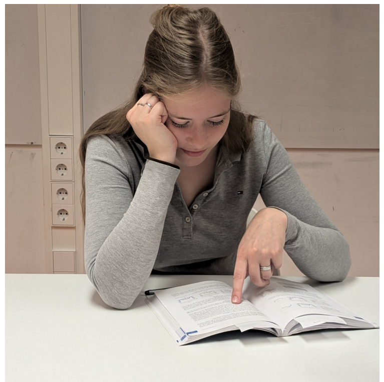
- Questionnaire about thermoforming

(orange) = Same in both tests

(grey) = Different in tests

Other than the setup in V2, there is no manual/instruction 'how to thermoform'. The setup will be pre-assembled and students only have to execute the forming step. Including assembly in the research scope woulld give too many variables.

Students willl only be provided with a part that has to be replicated and the assembled experiential machine. The participants have to experience themselves.



Students following direct instruction

Material

- The V3 Experiential Manufacturing Machine, see configuration explanations in this chapter (prototype V3)
- Consent form (see appendix B.1)
- Mini lecture video (see link below)
- Factory video (see link below)
- Experience questions (see appendix D.1)
- Knowledge test (see appendix D.2)

SCAN ME

https://youtu.be/DMaPSvjcZcI

Mini-video lecture of Thermoforming (made by me)

SCAN ME

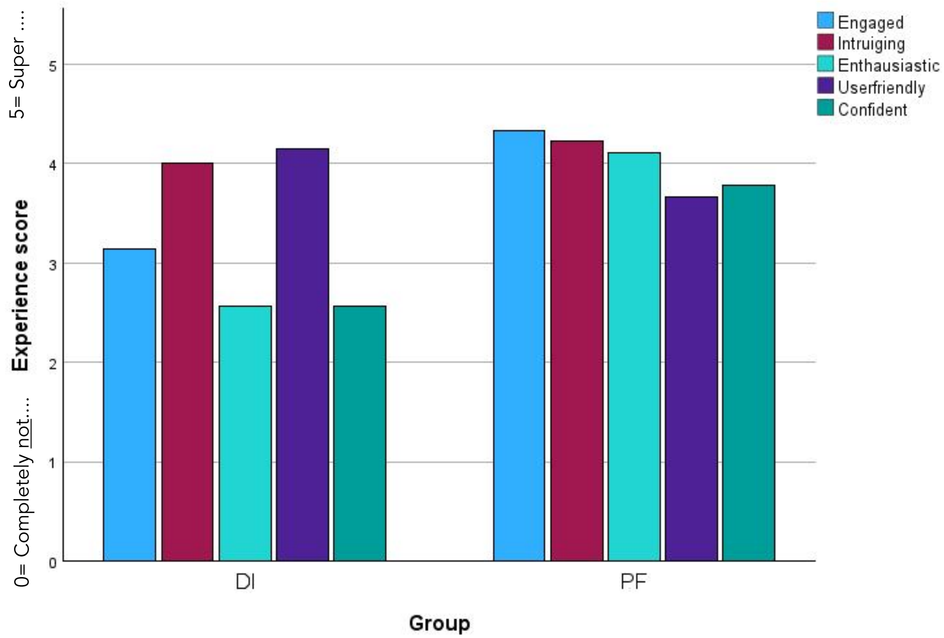
https://youtu.be/UBSnFEUq-tE

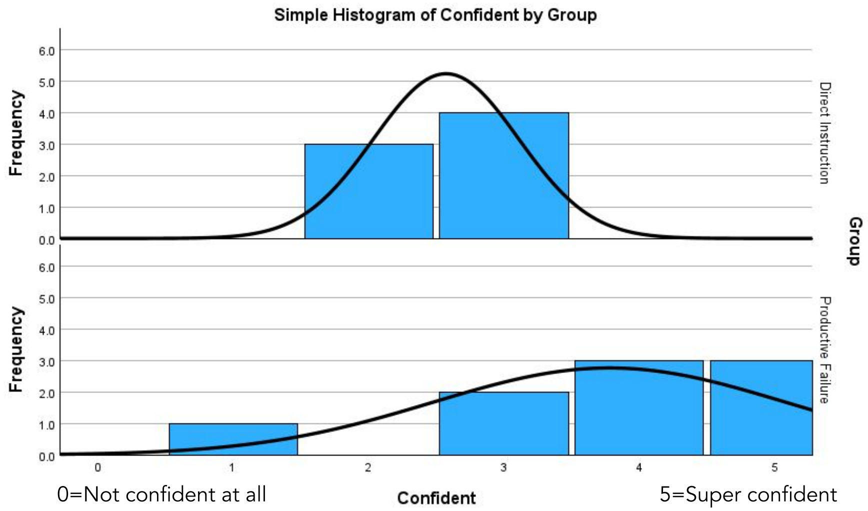
Video of Thermoforming in factory

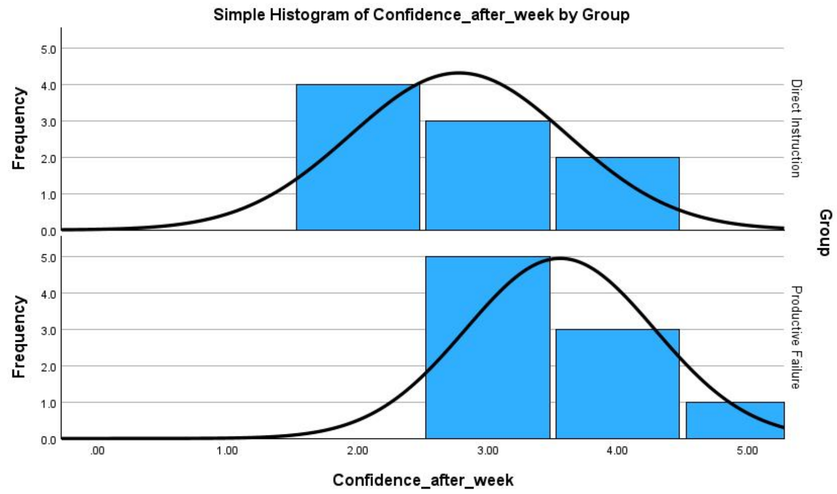
Results

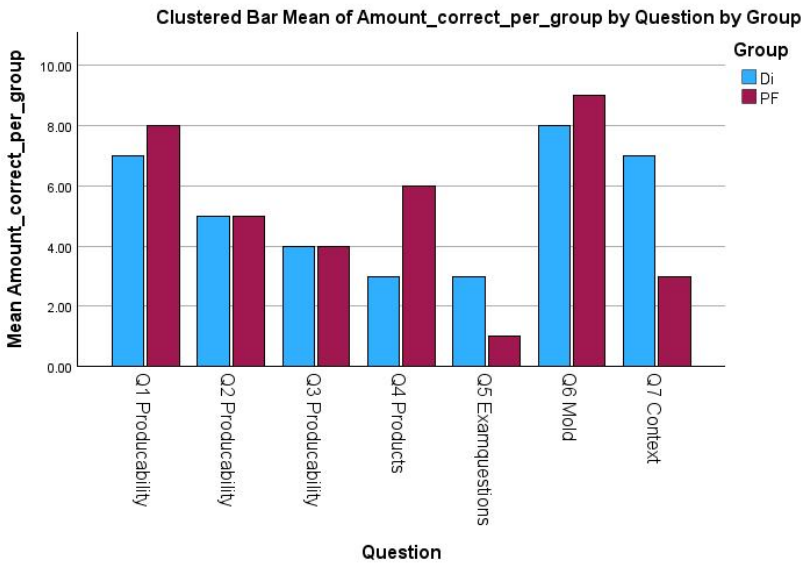
The results of students' perception/experience show that there is a significant difference in all experience questions. (for the full results please be referred to appendix D.3). All mean, except user-friendliness score higher score in the PF (group A) compared to the DI group (B). This means 'more confident' (see Appendix D.2 for exact questions). This means that the experiential setup scores higher in terms of positive perception of the learning process than direct instruction.

Something that is very interesting is that the deviation is greater for the experiential group meaning that some students really feel confident after the method and other really don't. This is true for almost all statement. When witnessing the participants in persons during all tests, I can confirm this. Some students, blocked, they did not know how to continue and solve the problem without external help.









The content based questions show that, on average there is <u>no significant difference</u> between the two approaches. However, Q7, which focuses on context, was answered much better by students who followed direct instruction. This is likely because the book provides a broader perspective on where this process can be applied. This broader context also led to some confusion in Q4, which asks which products can be made using a particular production process, that resulted in a higher percentage of correct answers for the Productive Failure group.

Students showing of their result.

Discussion

The vision of this project was to create an educational setup that actively engages students by being intriguing, exciting, versatile, and user-friendly. We can conclude with ease that this vision statement is met. On all, except user-friendliness the experiential setup scores higher!

Validated - The setup actively engages students and improves user experience

↓

dv-7 Enhancing education experience

The big deviation needs to be addressed in a redesign of the workshop material. It is expected that the background-knowledge can be too limited for some participants that they completely block.

Insights - Prior knowledge and learning preference differs. An initial struggle is oké but it does not have to be a block

↓

New Requirement - 40. The setup should facilitate solutions for students with limited prior knowledge.

On content aspect it is conclude that there is no significant difference. This workshop structure is however only tested for the first time and has to be adjusted and improved.

Validated - The setup does not (yet) enhance education over DI

↓ Not met

~~vv-5 - Enhances education results~~

Limitations

Disclaimers

- We are now actually testing productive failure compared to direct instruction. And not just the experiential machines compared to no experiential machines. Another option could also be to test both productive failures with only the machine as a variable. Designing a productive failure workshop about thermoforming is a design process on its own. Therefore, this is left out of scope but could reduce the variables in the future.

- Retention of the content is now assessed only 1-1.5 week after the workshop. For better insights into the results, this time is increased. For example, you might choose to measure retention on a monthly, quarterly, or annual basis. By analysing retention over different time periods, you can gain a comprehensive understanding of customer behaviour and make data-driven decisions to improve retention rates. (Zingerline, 2024)

- Finding good participants turns out to be more important than expected. The requirements for now were a mix of men and women. Bachelor students who did not know what thermoforming was. As a result, bachelor students who, for example, study public administration, also participated. During testing, you notice that they have a different mindset and are therefore not necessarily the right target group. To recruit participants, mainly students who find practical learning interesting signed up. For a good follow-up study, you really need students who are new to IDE and have no prior knowledge but do have an interest in industrial design.

Recap

Three fully functioning manufacturing prototypes are made.

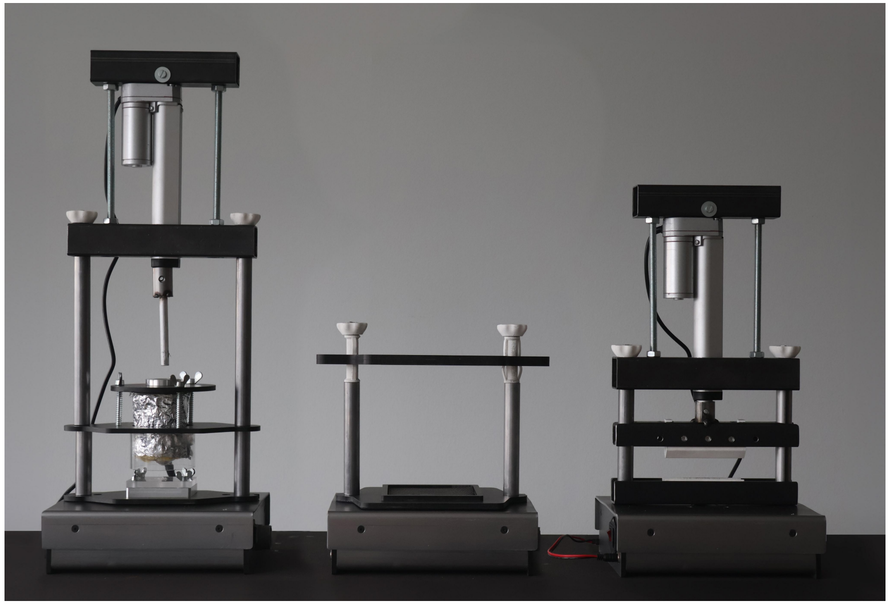
For a summary, you can open this link https://www.instructables.com/Experiential-Manufacturing-Machines-for-Education/

To test if the setup functioned as intended, user test V3 is conducted that compared the V3 Experiential Manufacturing Machine integrated in a Productive Failure Workshop to Conventional Learning without Experiential Machine within the same timeframe.

The results are interesting, the goal of this project was to improve deeper conceptual understanding and knowledge retention of manufacturing education. There is no significant difference, between the experiential setup and direct instruction the content based (exam) questions.

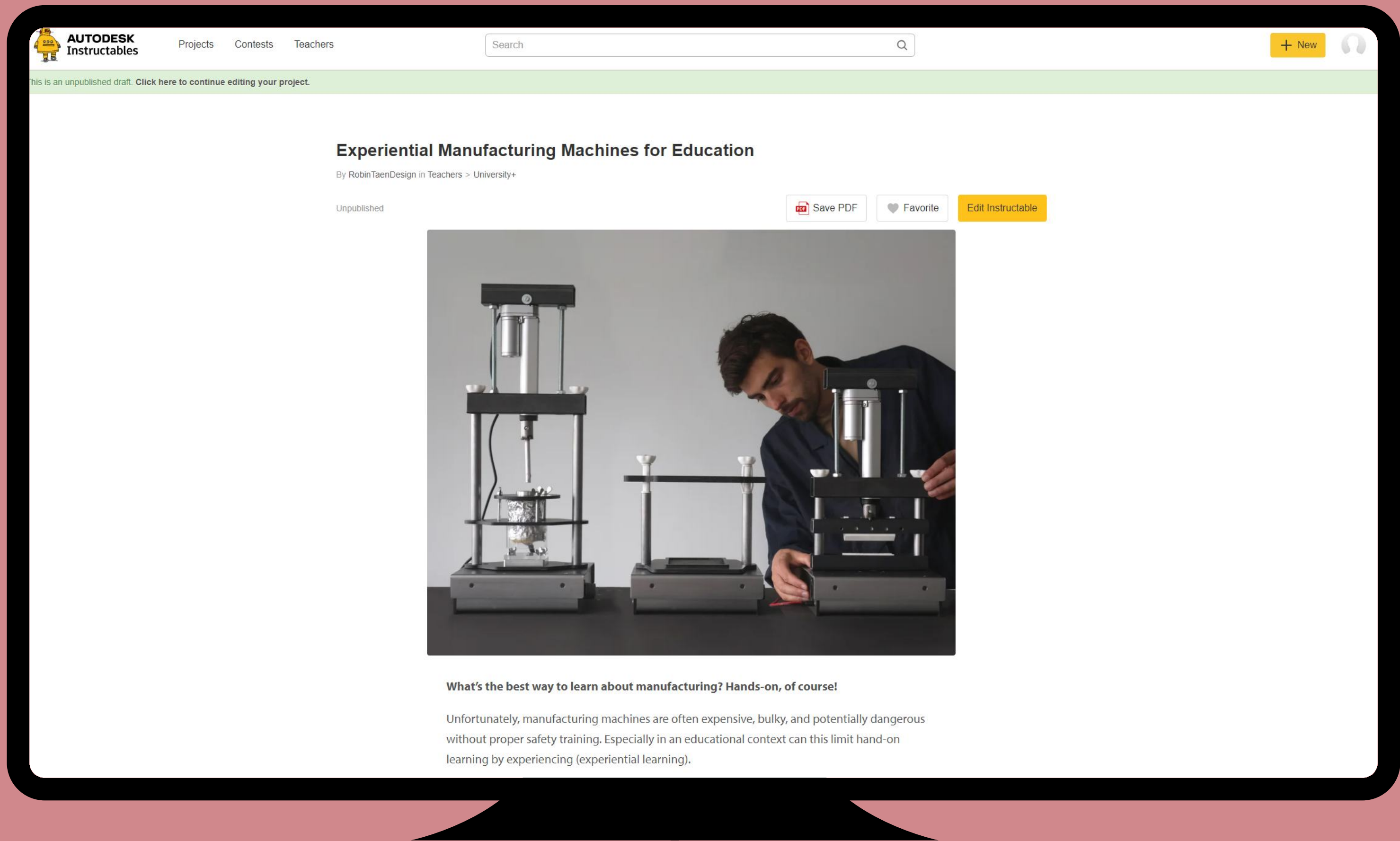
However, students perception is significantly higher. An educational setup was envisioned that actively engaged students by being **intriguing, exciting, versatile, and user-friendly**. On all, except user friendliness the experiential setup scores higher than direct instruction.

Chapter 1 in the next phase describes why this design is valuable according the three different value characteristics; desirability, viability and feasibility.



For the full list of requirements and value characteristics please be referred to appendix D.4

Justification & Follow-up
How to proceed



1. Conclusion

During the whole project value characteristics are retrieved from insights and requirements. This chapter will summarize and conclude if the Experiential Manufacturing Machine (EMM) adds value to IDE.

Desirability, Do we need or want it?

This report has shown that IDE students struggled to apply their engineering knowledge in capstone design projects and that there is a need for education to align better with the (new) IDE bachelor program (Problem Definition p.3). Experiential Learning (EL) and Productive Failure (PF) suit this new program well (Educational approaches p.9). User test V2 (p.26) and V3 (p.26) have shown that the EMM functions well, both as a stand alone setup and integrated in a PF workshop (dv-1 and dv-2).

User test V3 results indicate that students find the EMM intriguing (dv-6), exciting (dv-4), and enhances confidence (dv-7) compared to traditional Direct Instruction.

The final design incorporates durable, rigid materials such as HPL, commonly used in educational settings, enhancing its educational appeal (dv-8). While currently only one colour is used, future designs will include more colour options to improve clarity during assembly and diversity between configurations. Due to the low purchase price and wide variance of implementations the machine will be very accessible for IDE students (dv-5).

On user-friendliness (dv-3) this design needs more development s

Overall we can conclude that the design is desirable and aligns with the new bachelor program and courses.

Feasibility, Can we achieve it?

The EMM has proved to be working and makes mini parts (fv-1), not only on paper on within a controlled context. Two configurations have been tested with students, (fv-6) that used the machine without manual or prior instruction in an educational workshop (fv-3). The third configuration, injection machine has yet to to be tested in the envisioned context.

The EMM is production ready (fv-4) and all parts can be ordered from local suppliers such as 247TailorSteel or Oceanz 3D. Parts can also be produced inhouse. With the full bill of materials a good estimate of the price has be given (p.26). For three configurations the total setup will cost €280, depending on the batch size and surface treatment. This is less than €95 euro per manufacturing technique (fv-5).

Due to its modularity and slim design, existing trolleys can be used to store and use the machines at the faculty of IDE. No extra space or logistics are needed (fv-8).

Unfortunately, a 100% safe design can not be guaranteed in this stage of the development (fv-2), since the machines are not CE-certified and therefore need further development. It is expected that this certification procedure will be easier due to the use of existing, unmodified CE-certified machines such as a heat gun or vacuum cleaner. It expected that all building blocks are there for seamless integration in IDE education. However this has not been tested (fv-7).

Viability, Can it be sustained over time?

The EMM keeps costs low, with production as cheap as €95 per machine (vv1), depending on batch size, surface treatment and setup (p.26). It uses off-the-shelf parts and simple manufacturing processes, ensuring low maintenance costs through in-house repairs (vv-2). The machine's versatility makes it suitable for multiple engineering courses such as Understanding Product Design, Materials & Manufacturing, and Advanced Prototyping, increasing the return of investment (vv-3).

Additionally, its versatility and modularity allows for future development and scaling of the design, adapting to various educational needs (vv-4). With the unique focus of this experiential setup on education it has character traits that are not seen on the market (vv-6).
By being highly disassemble/reparable and the use of durable materials the MME can be seen as sustainable. The storage solution, using foam, could however been improved and needs more research and development on the sustainable aspect. This technique is chosen to create overview for students and educators. A structured overview will reduce frustration, reduce parts gone missing and enhance the lifespan (vv-7).

User tests V3 results show that there are no enhanced educational results yet (vv-5). Compared to traditional Direct Instruction. More testing has to be conducted. Also over a longer life span to test students retainment.

Value characteristics

Desirability values

- dv-1 Facilitate experiential learning
- dv-2 - Adaptable to courses with a productive failure approach
- dv-4 - Exciting design
- dv-5 - Accessible design
- dv-6 - Intriguing design
- dv-7 Enhancing education experience
- dv-8 - Educational setup Appeal

To be improved

- dv-3 - User-friendly design

Feasibility values

- fv-1 - Making real products/parts
- fv-3 - Working prototype (TRL 7-Prototype demonstration in operational environment)
- fv-4 - Production ready
- fv-5 - Cost estimate
- fv-6 - User tested
- fv-8 - Logistical, portability and storage

To be improved

- fv-2 - Safe design
- fv-7 - Integration in IDE education

Viability values

- vv-1 - Low investment costs.
- vv-2 - Low maintenance costs.
- vv-3 - High return of investment
- vv-4 - Versatile and Scalability
- vv-6 - Market alternatives/demand
- vv-7 - Sustainability

To be improved

- vv-5 - Enhances education results

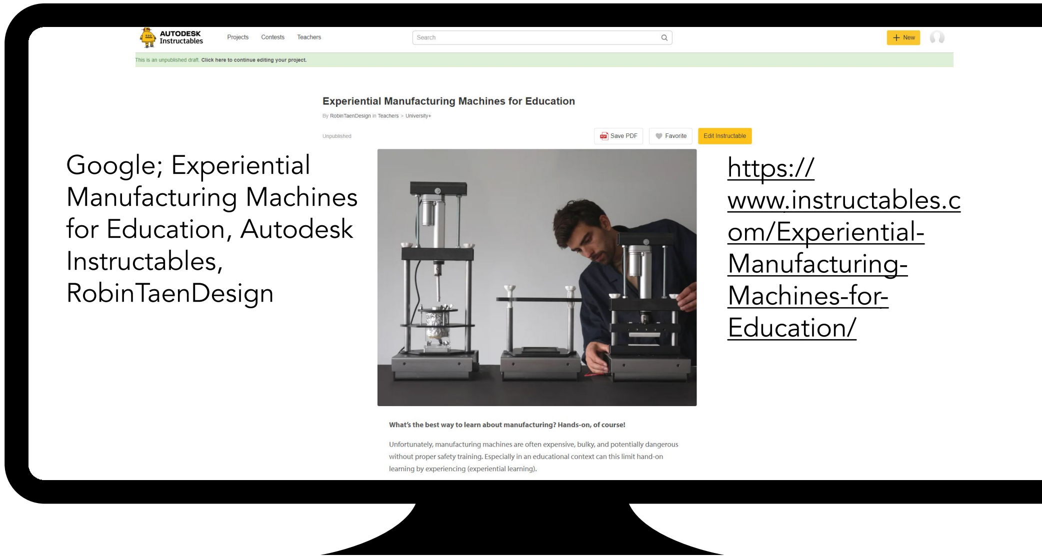
For a full overview of all requirements that are connected to the value characteristics, please be referred to appendix D.4

2. Next steps

Open Educational Resources

By sharing this design open source, more configurations can be developed and the design can be improved and adjusted for different contexts. Open source in the the context of education is called Open Educational Resources (OER), this are teaching, learning, and research materials that reside in the public domain or have been released under an open license that permits their free use and re-purposing by others. (Open Education - Creative Commons, 2024).

There are many different platforms. In appendix A.1 you can see an overview of different platforms and their focus. To report this project, the platform Autodesk Instructables has been chosen. Due to its associability and the current phase of the project. As soon as the machines are tested in more workshops OER commons would be the platform to share the educational package including the MME as resource since their target group are professional institutions.



Google; Experiential Manufacturing Machines for Education, Autodesk Instructables, RobinTaenDesign

https://www.instructables.com/Experiential-Manufacturing-Machines-for-Education/

User testing at the TU Delft

Even though, 3 user tests have been conducted more testing is needed to test the design on, educational enhancement. Usability, workshop materials, teacher perception etc. I envision that this can be done graduate students like Kiet and I or completely new students with a fresh look. Also the AED master course could be a very good resource to develop the designs further.

Production

The EMM is production ready and all parts can be ordered from local familiar suppliers such as 27 tailor steel or Oceans3D. Parts can also be produced inhouse in the PMB. Currently it only has been produced inhouse as prototype and verified with Tailor steel's online quote tool, Sophia. To test tolerances and manufacturing issues a small batch has to be ordered and tested.

Safety analysis

As stated in the conclusion is a proper CE-test needed to make this design safe to work with. The designs depending on the configuration use external machines such as a heat gun or vacuum cleaner that are CE-certified. Therefore there is hope that the machines don't need too much modification. This is something for future developers to research.

Hint cards

User test V3 showed that some students got completely stock. Kirschner, Sweller, and Clark (2006) discuss that when students learn science in classrooms with pure-discovery methods (EL) and minimal feedback, they often become lost, frustrated, and their confusion can lead to misconceptions.

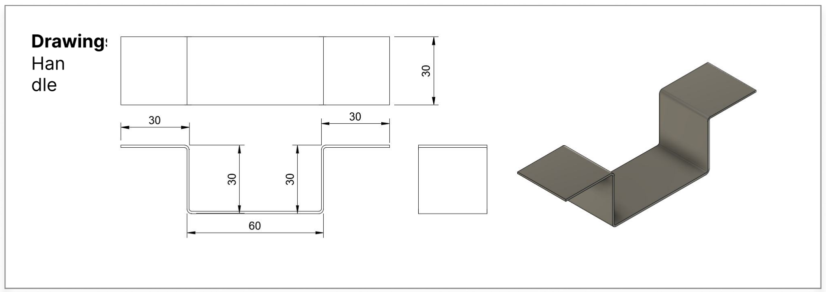
The results showed that is not always true but for the few it can make learning frustrating and inefficient. As one participant noted; “I rather in this stage just read about the process than proceed trying”. I think that for these instances guidance cards can be created. Students can, if they want have a peek at the way to do it or results.

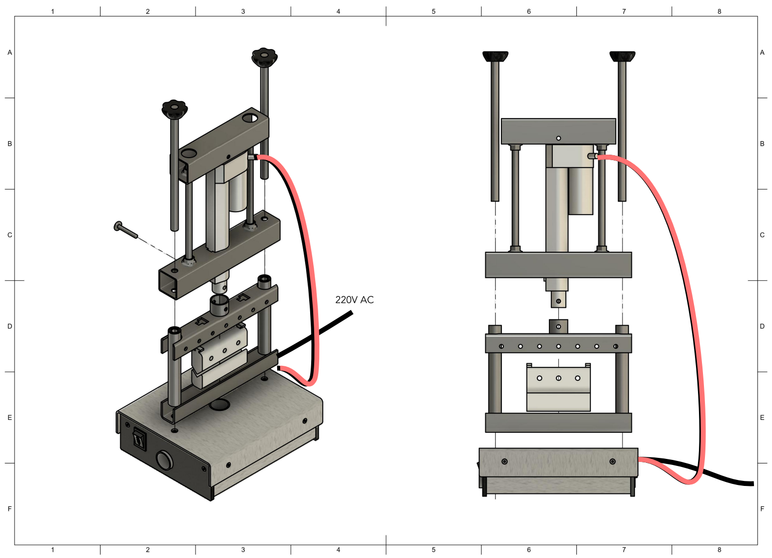
If this would be implemented in the workshop, then the workshop sturcture also has to be adjusted slightly.

How this design will be embodied is out of scope for this project, this is only an idea.

Manuals

Several manuals have been created. Requirement - 4. states that >80% should be able to use the setup without a manual. This still means that for the other 20% some kind of manual has to be available. More user testing is needed to find the perfect format.



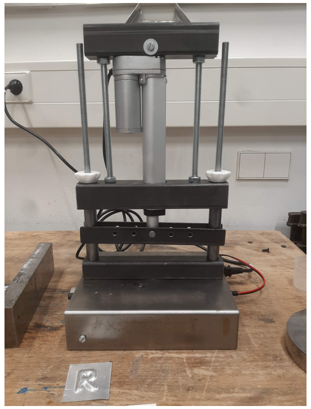


Future configurations

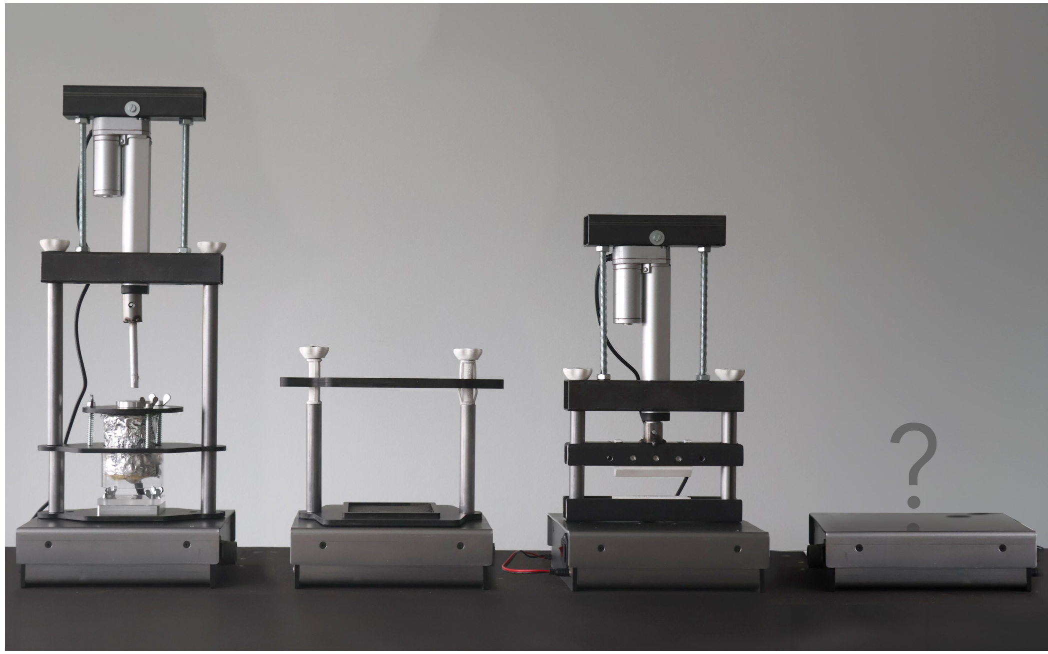
When looking at the manufacturing choice on page 26 or appendix we see that there are many ways in which more configurations can be added. With the existing used actuators, Linear actuator (press) heat gun, PTC element (heat source) and the vacuum cleaner (negative air pressure) 16 other configurations can be developed.

- Extrusion
- Sheet stamping, punching
- Guillotining
- Punching, perforating, nibbling
- Vacuum bag composite molding
- Lost wax casting
- ......and 10 more.....
-

When adding a rotational-spinning force we can make the list almost complete and develop 12 more manufacturing methods



I have conducted a little further research into future configurations. Here is a small example: the pictures show the possibilities of stamping aluminium. By just printing two new 3D printed parts, the metal bending configuration can be transformed into a new manufacturing configuration.



This drill head could be a possible add-on to create a rotational spinning force (Amazon.nl, n.d.).

3. Personal reflection

I have really enjoyed this project and have learned a lot. I liked the assignment and the design freedom it offered. During the project I felt both comfortable and challenged. By using a different design approach than the conventional waterfall model or double diamond, I felt that I was able to develop and excel, which resulted in both an increase in the quantity and quality of my work. Up till now deliverables are often shaped in a way where the waterfall methods only suits the course. I truly enjoyed developing my own way of working. With this, my strength and weaknesses also came to light. I love the iterative process, hands-on work and technical details. I also really enjoy testing with students, will it work? Why does the design fail? Instead getting frustrated when the design fails I get excited, 'I did not know that this was even a possibility to misunderstand'. Sometimes I struggled with the analysis of the results. This was often due to, too many different types of (sub) questions and a too broad research question, on the other hand did this give me a lot of insight in a short time.

What I like less is documenting, I really had to push my self to document all my findings and insights. As designer you make so many decisions per day that its hard to show on what criteria/arguments you make those choices. Looking back at the whole process, I do not feel that I miss steps, but I might have missed some argumentation in the final document.

Planning went well, I have felt in control and met my own expectations. Overall im proud of my result and see myself continuing with the project in the future.

Thanks for reading this report and I hoped you enjoyed.

Most enjoyable
Technical iterations and production

I spent a big part of my project in the PMB developing the iterations. Countless improvements and decisions to make the design better. I really enjoy this and this iterative approach met my expectations. My goal was to have used all machines in the PMB before I graduate, and I have! This hands on approach kept me motivated and really improved the design.

Most Surprising
My passion for education and testing

I always think testing preparation takes too long. However, this time I could do it on my own terms. I just placed the machine in the central hall, instead of finding participants, the participants came to me! This was very nice to see. Additionally, it was very intriguing to observe how people learn. Some things seem so obvious yet students struggle with it. To figure this out was a very exciting puzzle.

Most challenging
Documenting scientifically

Contrary to the statement above, I found it challenging to scientifically document all the results. I tried my best to create three stand-alone research papers and learn more about visualizing the gathered data. In hindsight, I see the value of this structured approach and visualizing insights for external parties.

References

References Analysis

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Appendices

Appendix A.1 - Project brief

TU Delft

DESIGN FOR our future

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME

Complete all fields and indicate which master(s) you are in

Family name	Taen	IDE master(s)	IPD ✔ Dfl SPD
Initials	R.S.	2nd non-IDE master	
Given name	Robin	Individual programme (date of approval)	
Student number		Medisign	
		HPM	

SUPERVISORY TEAM

Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Bas Flipsen	dept./section	SDE
mentor	Tobias Hebbink	dept./section	DOS
2nd mentor			
client:			
city:		country:	
optional comments			

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

Name Bas Flipsen Date 4-04-2024 Signature

CHECK ON STUDY PROGRESS

To be filled in **by SSC E&SA** (Shared Service Centre, Education & Student Affairs), after approval of the project brief by the chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total ____ EC

Of which, taking conditional requirements into account, can be part of the exam programme ____ EC

★	YES	all 1st year master courses passed
	NO	missing 1st year courses

Comments:

Sign for approval (SSC E&SA)

Kristin Veldman

Name K. Veldman Date 11-04-2024 Signature

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	★	Supervisory Team approved
NO		Supervisory Team not approved

Comments:

Based on study progress, students is ...

★	**ALLOWED** to start the graduation project
	NOT allowed to start the graduation project

Comments:

Sign for approval (BoEx)

Monique von Morgen

Name Monique von Morgen Date 24/4/2024 Signature

introduction (continued): space for images

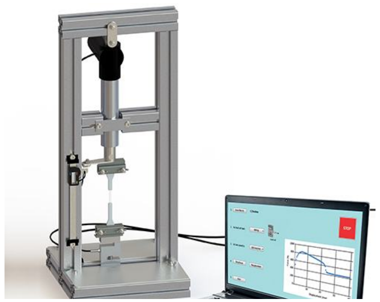


image / figure 1 Low-end tensile tester (LETT), developed by the TU Delft

image / figure 2 Precious plastics, simple and cheap injection moulding machine

Personal Project Brief – IDE Master Graduation Project

Name student Robin Taen

Student number 4853962

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Experiential setup for students

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

The Industrial Design Engineering BSc program at TU Delft is shifting its focus, reducing its emphasis on product engineering. However, foundational engineering principles and physical prototyping remain essential aspects of an industrial designer's knowledge. The Onderwijs- en Examenregeling (OER) also states that students have to be able to apply knowledge of mechanics, materials, and manufacturing for design choices in product embodiment to reach the required performance of a product (or component).

Therefore two obligatory technical courses remain in the curriculum. "Understanding Product Engineering" and "Product Engineering", where students are thought the fundamental engineering principles. Students also have the option to follow the elective courses "Materials and Manufacturing" and "Design Engineering contest" or the minor "Advanced Prototyping" that will also focus on this domain.

Due to the limited time and resources most courses are primarily limited to a theoretical learning approach. Educators see that there is a pressing need for a more experiential understanding of the theory. Currently one experiential setup is available, the LETT (a simplified tensile tester machine), where students get hands-on experience on material properties such as Young's modulus and yield strength. There are much more engineering principles, particularly those related to manufacturing techniques, product architecture, and statics that can be explained with experiential setups.

The setting in which these courses are held are different. It ranges from one afternoon where 350 students at the same time have to get an understanding of the subject, to a minor where students can master one specific aspect over a course of a few weeks. There are currently no other affordable and safe of-the-self experiential machines available with this educational purpose in mind.

→ space available for images / figures on next page

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

The problem aimed to be solved is that most material is only taught by the conventional theoretical learning approach (such as lectures, books, and equations on paper). This conventional learning approach poses limitations, thus limiting real concept understanding, knowledge retention, and an overall intuitive 'feel' for engineering principles.

By developing resources for experiential learning and a productive failure learning approach, we expect that we can enhance learning in the engineering bachelor courses.

Sources:
Kapur M., & Bielaczyc, K. (2012). Designing for Productive Failure. Journal of the Learning Sciences, 21:1, 45–83.

Gadola M, Chindamo D. Experiential learning in engineering education: The role of student design competitions and a case study. International Journal of Mechanical Engineering Education. 2019;47(1):3-22. doi:10.1177/0306419017749580"

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence)
As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Develop an experiential setup which can be used to enhance learning in the engineering bachelor courses.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

This project will employ an iterative and hands-on approach. Using an Agile structure, complemented by occasional design sprints.

To create an applicable setup, prototypes and hypothesis will be tested with bachelor students to determine the relevance, user-friendliness, and level of challenge, while also capturing their interest. The primary focus of this project lies in the embodiment and testing phase.

The project ends with a functioning full-scale prototype and an interface/workshop materials focused on the educational setting.

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a ***kick-off meeting, mid-term evaluation meeting, green light meeting*** *and* ***graduation ceremony****. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	15 March 2024
Mid-term evaluation	14 May 2024
Green light meeting	27 June 2024
Graduation ceremony	3 September 2024

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

I am passionate about tackling technical design challenges and reframing problems into innovative solutions. I enjoy (digital) fabrication and I am eager to further improve my skills on this aspect as an industrial designer. My goal is to cultivate practical knowledge and hands-on expertise in building, designing, and prototyping products, with a strong emphasis on real-world application and manufacturing.

Throughout both my bachelor's and master's studies, I have consistently been drawn to the engineering and practical aspects of the curriculum. Whenever possible, I ensured to utilize the PMB. Additionally, outside of my studies, I have been involved in building various projects. I observed that this wasn't the case for many of my fellow students. Despite their interest, there often seemed to be a barrier preventing them from creating physical prototypes, resulting in less familiarity with basic engineering principles."

Throughout the project, I aim to use decision-making tools to evaluate what design directions have priority for the end user. Currently, I am using tools such as the Weighted Objectives Method and the Datum Method. In this project, I have the ambition to experiment with new methodology in decision making.

Appendix A.1.1 - Project Objective Iterations

Original Design brief

Original Problem definition
The problem aimed to be solved is that most material is only taught by the conventional theoretical learning approach (such as lectures, books, and equations on paper). This conventional learning approach poses limitations, thus limiting real concept understanding, knowledge retention, and an overall intuitive 'feel' for engineering principles.

By developing resources for experiential learning and a productive failure learning approach, we expect that we can enhance learning in the engineering bachelor courses.

Original Scope
All bachelor engineering courses and its subjects

Original Assignment
Develop an experiential setup which can be used to enhance learning in the engineering bachelor courses.

Summery v0
What do I want to provide students?
Provide students with an experiential setup to improve education of the engineering bachelor courses.

Why?
Conventional learning approach poses limitations, thus limiting real concept understanding, knowledge retention, and an overall intuitive 'feel' for engineering principles.

Statements during v1

Problem definition
conventional learning approach poses limitations, thus limiting real concept understanding, knowledge retention, and an overall intuitive 'feel' for engineering principles. **During analysis especially opportunities and limitations of manufacturing and materials are not experienced.**

By developing resources for experiential learning and a productive failure learning approach, we expect that we can enhance learning in the engineering bachelor courses.

Scope
Subjects in the bachelor engineering courses that reference to;
OER - Materials and Manufacturing 2.2.2 (UPE, M&M, AP)
Architecture evaluation 2.5.1 (UPE, AP)
Architecture specification 2.5.2 (UPE, AP)
Environmental sustainability 3.3.2 (UPE, M&M, AP)

Assignment v2
Enhance learning in engineering bachelor courses by creating an experiential setup that gives students a **hands-on feel and understanding of materials and their manufacturing processes, as well as their opportunities and limitations for embodiment design.**

The setup has to be able to be used with different Bloom levels.

Summery v1

What do I want to provide students?
Provide students with an experiential setup to autonomously learn the reasons why materials and their production processes are used, as well as their limitations and possibilities.

Why?
Real concept understanding and a intuitive ‘feel’ for materials and production processes seems to be missing in the obligatory courses.

Statements during v2

Problem definition
conventional learning approach poses limitations, thus limiting real concept understanding, knowledge retention, and an overall intuitive 'feel' for engineering principles. **During analysis especially opportunities and limitations of manufacturing and materials are not experienced.**

By developing resources for experiential learning and a productive failure learning approach, we expect that we can enhance learning in the engineering bachelor courses.

Vision
The IDE students sense for materials and production methods is very limited in the bachelor. By provide students with an experiential setup to autonomously learn the reasons why materials and their production processes are used, as well as their limitations and possibilities. Deep concept understanding, knowledge retention, and an overall intuitive feel of engineering principles will be formed.

Goals

- Enhance learning in engineering bachelor courses by creating an experiential setup that gives students a hands-on feel and understanding of materials and their manufacturing processes, as well as their opportunities and limitations for embodiment design.
- The setup has to be able to be used within different context, in a course environment and in out of pure student curiosity.
- The setup should educate students on different Bloom levels.

Statements during v3

Problem definition
The current availability of educational tools and research constrains course coordinators from fully implementing the envisioned productive failure and experiential learning approaches in the first-year "Understanding Product Engineering" course in Industrial Design Engineering. This limitation forces reliance on conventional methods, such as lectures and other passive learning approaches, which hinder deep concept understanding, knowledge retention, and an overall intuitive feel of engineering principles.

Assignment
Provide students with an experiential setup to autonomously learn the reasons why materials and their production processes are used, as well as their limitations and possibilities. Ultimately leading to deeper conceptual understanding, enhance knowledge retention, and cultivate an overall intuitive feel for these subjects.

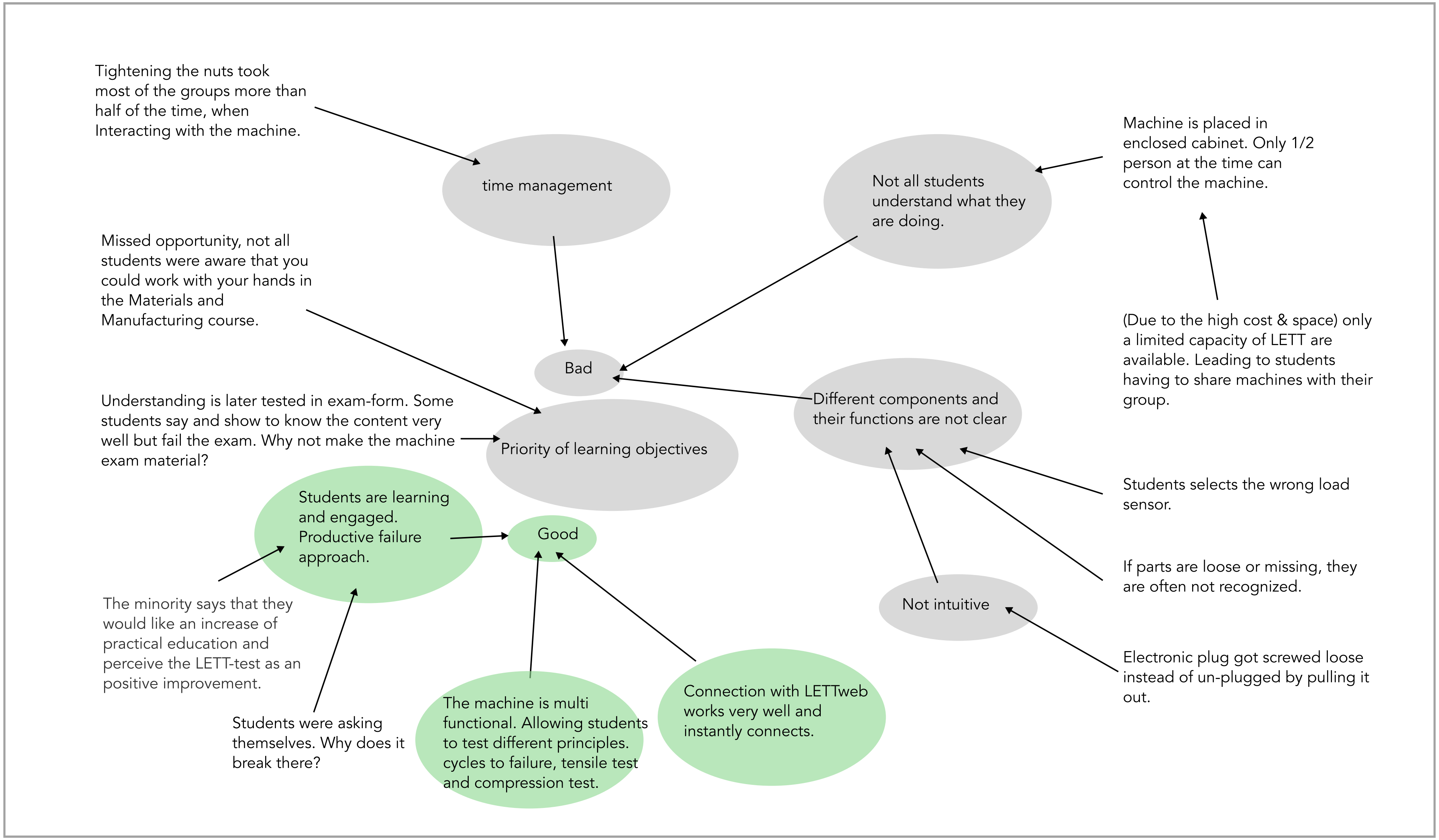
Vision
A setup is envisioned that actively engages students by being intriguing, exciting, versatile, and user-friendly. By utilizing a productive failure and experiential learning approach, this setup will enable students to gain a deeper understanding of production processes. Designed to be cost-effective and easy to maintain, it will be seamlessly integrated across the IDE bachelor's program.

Goals

- Enhance learning in engineering bachelor courses (main focus on UPE) by creating an experiential setup that gives students a hands-on feel and understanding of materials and their manufacturing processes, as well as their opportunities and limitations for embodiment design.
- The setup has to be able to be used within different context, in course environments and as free standing setup.
- The setup should be able to educate students on different Bloom levels.

Appendix A.2.1 - Visualised LETT analysis

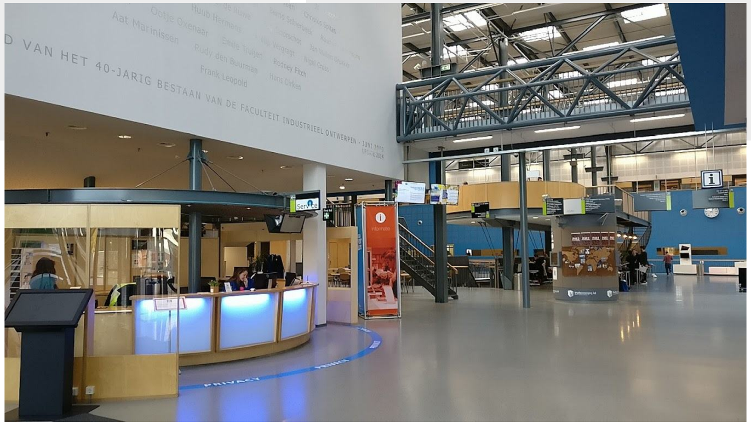
To analyse both what is working well and what could be improved, I use my own technique (or at least one I am unaware of others using) where I visualize observations and trace them back to their origins. These insights can then be applied to the design of new experiential setup.



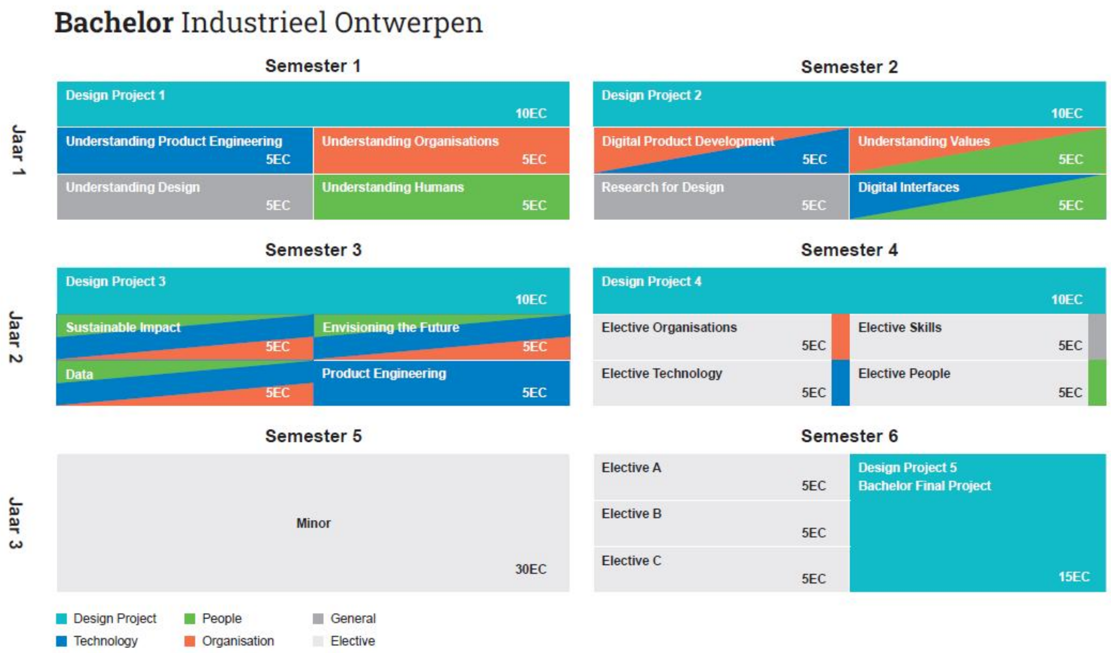
Appendix A.2.2 - IDE helpdesk customer journey

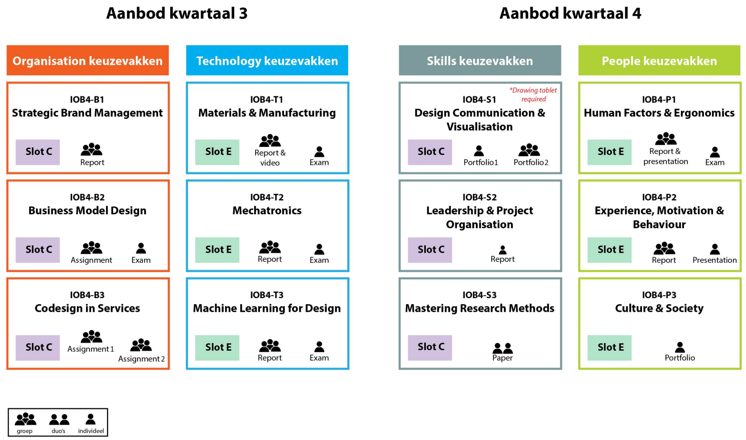
This customer journey (Van Boeijen et al., 2014b) shows steps and barriers for students.

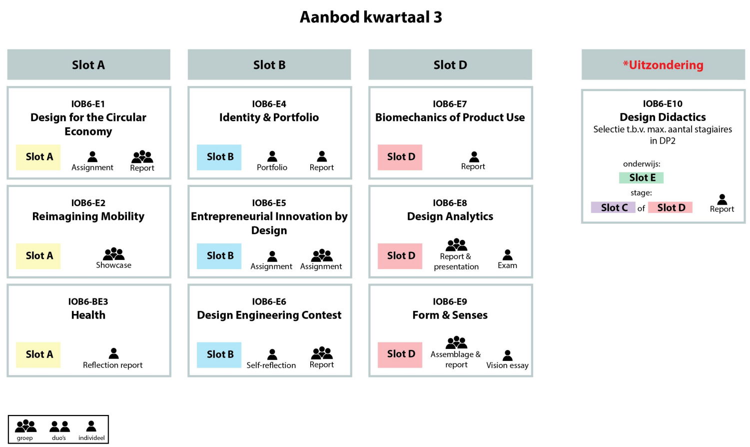
	Pre-Helpdesk	registering Helpdesk	Using borrowed tool	Handing back borrowed tool at Helpdesk
Physical barriers	• LETT is only available at IDE during study hours.	• All parts are manually checked by people behind the desk		
Mental barriers	• Unaware what you can borrow. • Unaware what is available		• Does not understand borrowed tool.	
Reasons why	• No online tool or data base • No overview of tools available. • No awareness due to poor publicity	• IDE is afraid that students will treat the tools irresponsible and possibly steal parts.	• No manual available	



Appendix A.3 - Course overview







Weekrooster

	Maandag	Dinsdag	Woensdag	Donderdag	Vrijdag
Ochtend	Slot A	Slot C	Slot E	Slot B	Slot D
Middag	Slot B	Slot D	Slot A	Slot C	Slot E

Appendix A.4 - UPE Course description and learning objectives

The learning objectives of the courses, directly copied form 'https://studiegids.tudelft.nl/'

UPE

Om producten in de fysieke wereld te ontwerpen moet een ontwerper de technische basisprincipes kennen van het product en zijn onderdelen. Een gestructureerde technische analyse van bestaande producten is daarbij nodig om deze kennis beter te begrijpen en toe te passen in een toekomstige ontwerpcontext.

Er bestaat een overweldigend aanbod aan materialen en productieprocessen, maar ook aan analysemogelijkheden om te voorspellen hoe producten (gaan) functioneren in verschillende situaties. Om wegwijs te worden in dit veld wordt de student geïntroduceerd in vijf technische aspecten van tastbare producten, namelijk: Functie, Productarchitectuur, Materialen, Productietechnieken en Modellering, gerepresenteerd in het zogenaamde Techniekwiel.

In dit vak staat het product centraal, van waarlangs het techniekwiel wordt doorlopen. Naast de functie van alle onderdelen in het product en de relatie tot elkaar, zal ieder onderdeel worden geanalyseerd op de meest voorkomende materialen en productietechnologieën. Daarnaast zal door middel van een systematische analyse van geometrie, uitwendige en inwendige belastingen, en de leer van spanningen en vervormingen de student inzicht krijgen in de technische haalbaarheid van onderdelen in de productarchitectuur.

Dit vak legt de relatie uit tussen materiaalgroepen en hun belangrijkste eigenschappen, de belangrijkste verschillende productieprocessen die daarbij gebruikt worden, en de kansen en beperkingen die dit biedt voor productontwerp. De student maakt kennis met deze aspecten door het routineus verkennen van een tastbaar product, het te begrijpen door middel van analyse en abstractie, en het te evalueren op de vijf aspecten van het Techniekwiel.

Als studenten het vak afgerond hebben, kunnen ze:

1. Semi-formele en formele methoden gebruiken om de productarchitectuur van producten te analyseren met betrekking tot technische en duurzaamheidsaspecten (2.5.1);

2. Analytische en experimentele methoden gebruiken om functionele en niet-functionele eigenschappen van een technische productarchitectuur te testen en te evalueren (2.5.2);

3. De basisprincipes van statica toepassen in productengineering o.a. vrije lichaamsdiagrammen en evenwichtsvergelijkingen (2.2.1);

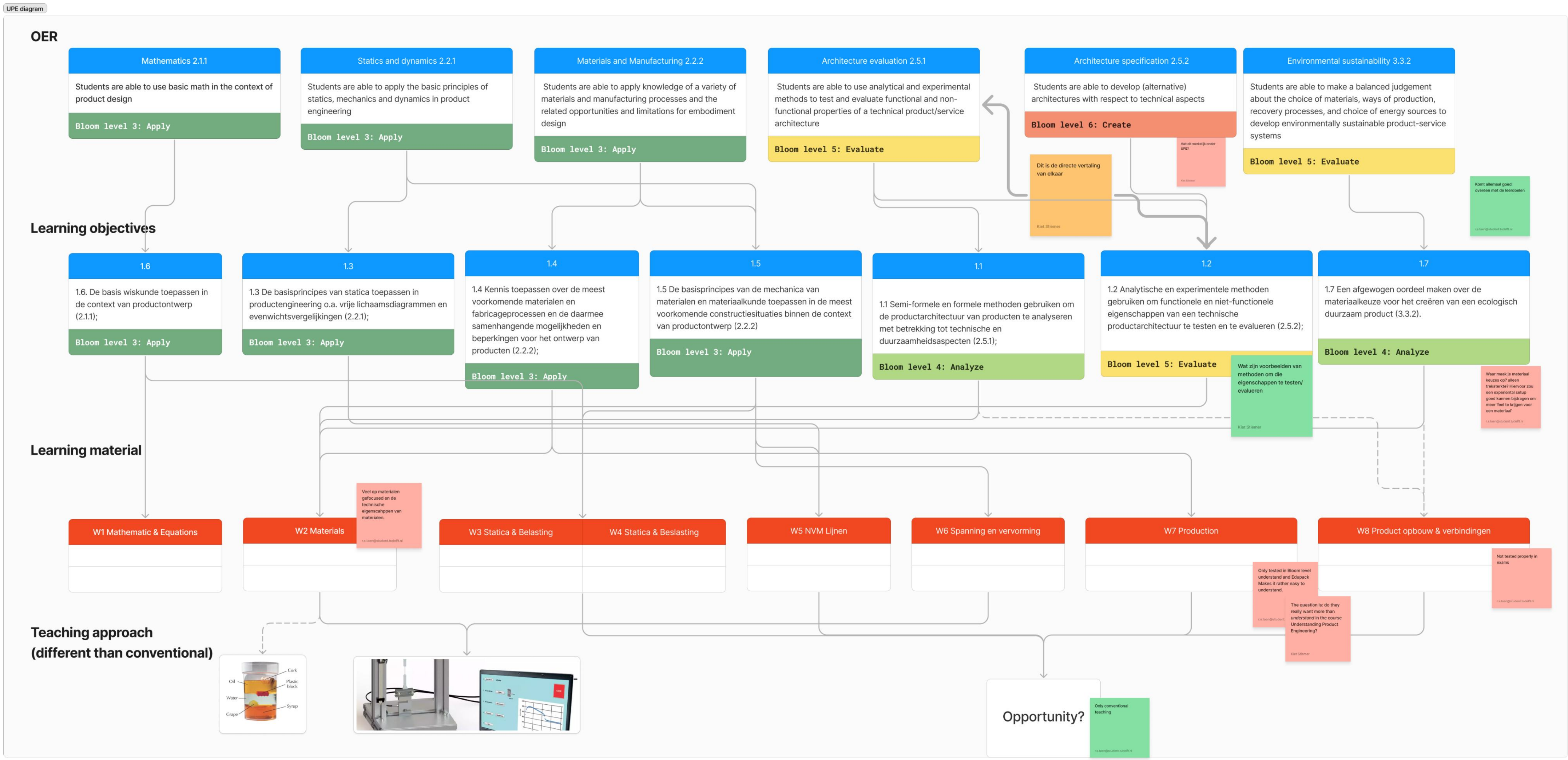
4. Kennis toepassen over de meest voorkomende materialen en fabricageprocessen en de daarmee samenhangende mogelijkheden en beperkingen voor het ontwerp van producten (2.2.2);

5. De basisprincipes van de mechanica van materialen en materiaalkunde toepassen in de meest voorkomende constructiesituaties binnen de context van productontwerp (2.2.2);

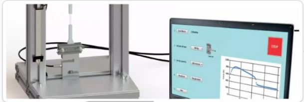
6. De basis wiskunde toepassen in de context van productontwerp (2.1.1);

7. Een afgewogen oordeel maken over de materiaalkeuze voor het creëren van een ecologisch duurzaam product (3.3.2).

Appendix A.5 - UPE Course analysis



UPE diagram



Opportunity?

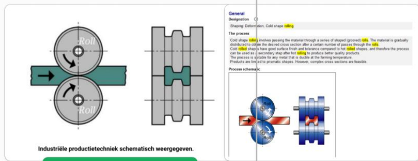
Only conventional teaching

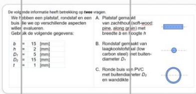
Exam questions

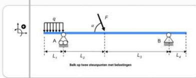
Tentamen 22/23

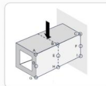
2	10	3	5	7	8	4	9	1	6
Materiaal (kunststof codes)	Milieuvriendelijkheid / materiaal	Statica (VLS herkenning)	Reactiekrachten /momenten	Statica + NVM lijnen	Spanning + NVM lijnen	Vervorming	Spanning en vervorming (en heel klein beetje verbindingen)	Productie	Productopbouw (maattekeningen)
Bloom level 2: understand	Bloom level 3: apply	Bloom level 2: understand	Bloom level 3: apply	Bloom level 3: apply	Bloom lvl 4: analyze	Bloom lvl 4: analyze	Bloom lvl 4: analyze	Bloom level 2: understand	Bloom level 2: understand

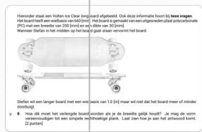
Meer op level 2 dan de her-23/24

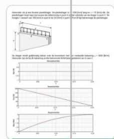


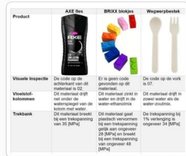












Tentamen 23/24

1	2	3	4	5	6	7	8	9	10	11
Productie	Materials, Spanning en vervorming	Vervorming	Statica	Spanning + NVM lijnen	Spanning + NVM lijnen	Spanning	Statica & Belasting + vervorming	Statica & Belasting + vervorming	NVM lijnen	Materials
Bloom level 2: understand	Bloom lvl 4: analyze	Bloom lvl 4: analyze	Bloom level 3: apply	Bloom level 2: understand	Bloom level 2: understand	Bloom level 2: understand	Bloom lvl 4: analyze	Bloom lvl 4: analyze	Bloom level 2: understand	Bloom level 2: understand

Hertentamen 23/24

9	7	2	4	5	3	6	8	10	1
Milieuvriendelijkheid	Materiaaldeterminatie	Statica	Reactiekrachten/ momenten	NVM lijnen	Buiging	Vervorming en materialen	Trekbelasting	Spanning	Productie
Bloom lvl 5: evaluate	Bloom lvl 4: analyze	Bloom level 3: apply	Bloom level 3: apply	Bloom level 3: apply	Bloom lvl 4: analyze	Bloom lvl 4: analyze	Bloom lvl 4: analyze	Bloom lvl 4: analyze	Bloom level 2: understand

Alleen op bloom level 2, understand getest

Opportunity?
Nog geen experiental learning

Opportunity?
Nog geen experiental learning

Opportunity; hands on feel for materials and manufacturing processes and their opportunities and limitations for embodiment design.

Opportunity?
Nog geen experiental learning

Opportunity?
Maar wordt weinig getoetst, werkelijk relevant?

Dit kunnen we even vragen

UPE diagram

Mathematics 2.1.1	Statics and dynamics 2.2.1	Materials and Manufacturing 2.2.2	Architecture evaluation 2.5.1	Architecture specification 2.5.2	Environmental sustainability 3.3.2
Students are able to use basic math in the context of product design	Students are able to apply the basic principles of statics, mechanics and dynamics in product engineering	Students are able to apply knowledge of a variety of materials and manufacturing processes and the related opportunities and limitations for embodiment design	Students are able to use analytical and experimental methods to test and evaluate functional and non-functional properties of a technical product/service architecture Architecture specification	Students are able to develop (alternative) architectures with respect to technical aspects	Students are able to make a balanced judgement about the choice of materials, ways of production, recovery processes, and choice of energy sources to develop environmentally sustainable product-service systems

Not tested
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Not tested
r.s.taen@student.tudelft.nl

OER Refelction

Retention

source; paper Bas Flipsen & Stefan

Test questions

Q1 Manufacturing

1. Memorizing manufacturing processes: consisting of 5 true or false statement on Shape Rolling and Die Forging;

`Bloom level 1: Remember`

Low bloom Level of 1 not 3. Not a proper question
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Q2 Free Body Diagram

2. Understanding of free body diagrams: consisting of nine optional Free Body Diagrams related to a stepladder against a wall;

`Bloom level 2: Understand`

Q3 Mechanics of Materials

3. Applying of mechanics of materials: where students had the choice between three beams with different cross-sections (rectangular, square, and round) made from three different materials (softwood, PVC, and low-carbon steel), and choose the option with the smallest elongation;

`Bloom level 3: Apply`

Q4 Internal forces

4. Understanding internal forces: consisting of four potential shear force diagrams related to a beam under load;

`Bloom level 2: Understand`

Q5 Internal stresses

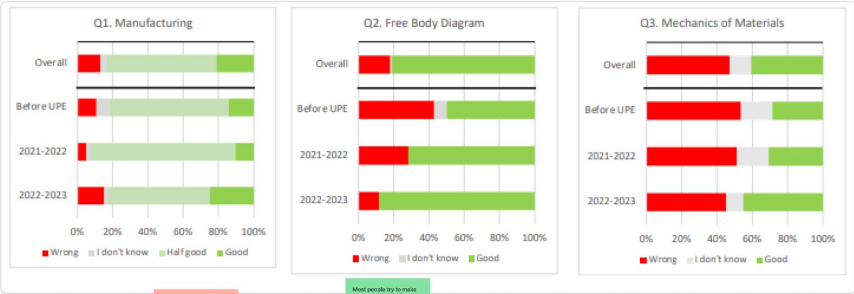
5. Understanding internal stressed caused by external forces and moments: where students had to calculate the internal shear stress and choose between 5 optional ranges (see figure 2);

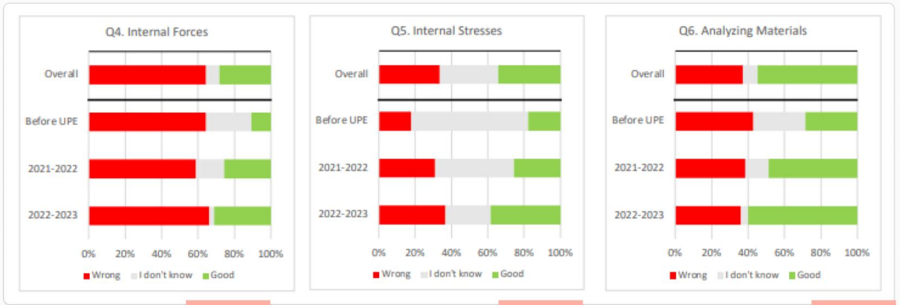
`Bloom level 2: Understand`

Q6 Analyzing materials

6. Analyzing materials: where students had to determine which material (HDPE, PP, PLA, or ABS) a product is made of based on the results of two experiments (buoyancy test and the tensile test)

`Bloom level 4: Analyze`





Lot of half good
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Most people try to make the question
r.s.taen@student.tudelft.nl

Low scoring
r.s.taen@student.tudelft.nl

Big 'don't know percentage' increases. Retainment low
r.s.taen@student.tudelft.nl

Big 'don't know percentage' increases. Retainment low. Amount of wrong stable.
r.s.taen@student.tudelft.nl

Conclussion;

The retention of knowledge reduces with each cohort, but some knowledge more than other. We see on average no difference between the cohorts on their exam grade, but the decrease of retention overall is present. Some knowledge retains longer than other. Lower levels of learning in the Bloom's taxonomy [10] seems to stick for longer, than higher up levels. The question concerning manufacturing is on the lowest Bloom's level Memory which seems to be the most constant over the years. When going higher up in the Bloom's level we see a decrease in retention, especially on questions concerning Bloom's level of Understanding (question 4 and 5), and on the level of Analysis (question 6). We notice that the newer cohort students are more confident to answer these questions but make as much mistakes as the other cohorts. This might be a possible indication for recollection but not knowing how to approach it. This could also be an indication that students are more confident to try even knowing that they might fail.

Agree with this conclussion
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Appendix A.6 - M&M and AP course descriptions and learning objectives

The learning objectives of the courses, directly copied form ‘https://studiegids.tudelft.nl/’

Materials & Manufacturing

On a global scale scientists and designers are looking for sustainable alternatives to carbon based organic materials; i.e., plastic sand polymers. New materials can be designed by combining waste material streams such as coffee waste, fruit waste, wood chips, starch and/or any other bio-based materials. In this course, we envision creating a green future starting with awareness about the materials around us.

The elective course Materials and Manufacturing running in quarter 3 in semester 4 aims to grow your awareness in building up such a future. You will explore how to make and combine waste materials as well as how to test their properties towards designing and making a product. You have different choices to define your product; for example, an (edible) lunch box, tablet / smart device covers, small company PR gift, or you can have a free choice as can be seen in the following table.

There are several stackholders/companies/material developers involved in this course; they are on board to share their journey from materials towards their product(s) and to help you to motivate your material and product of choice; material developers such as fruitleather Rotterdam, TU Green village, Ubuntoo (the environmental solutions platform), Bambooder biobased fibers, NPSP biocomposites and more.

You will learn appropriate tools which are needed to design with such new (and often not yet existing) material composites. How can you best model, make and test a product made by a new material designed by yourself? Manufacturing, testing and user aspects of the case studies will be topics in this elective.

The content of this course is relevant for you, because you will gain knowledge and insight on how selection of appropriate manufacturing techniques and of materials will condition the design of a product. The performance (technical and experiential) of finished products is ultimately determined by underlying materials and manufacturing characteristics.

Advanced prototyping

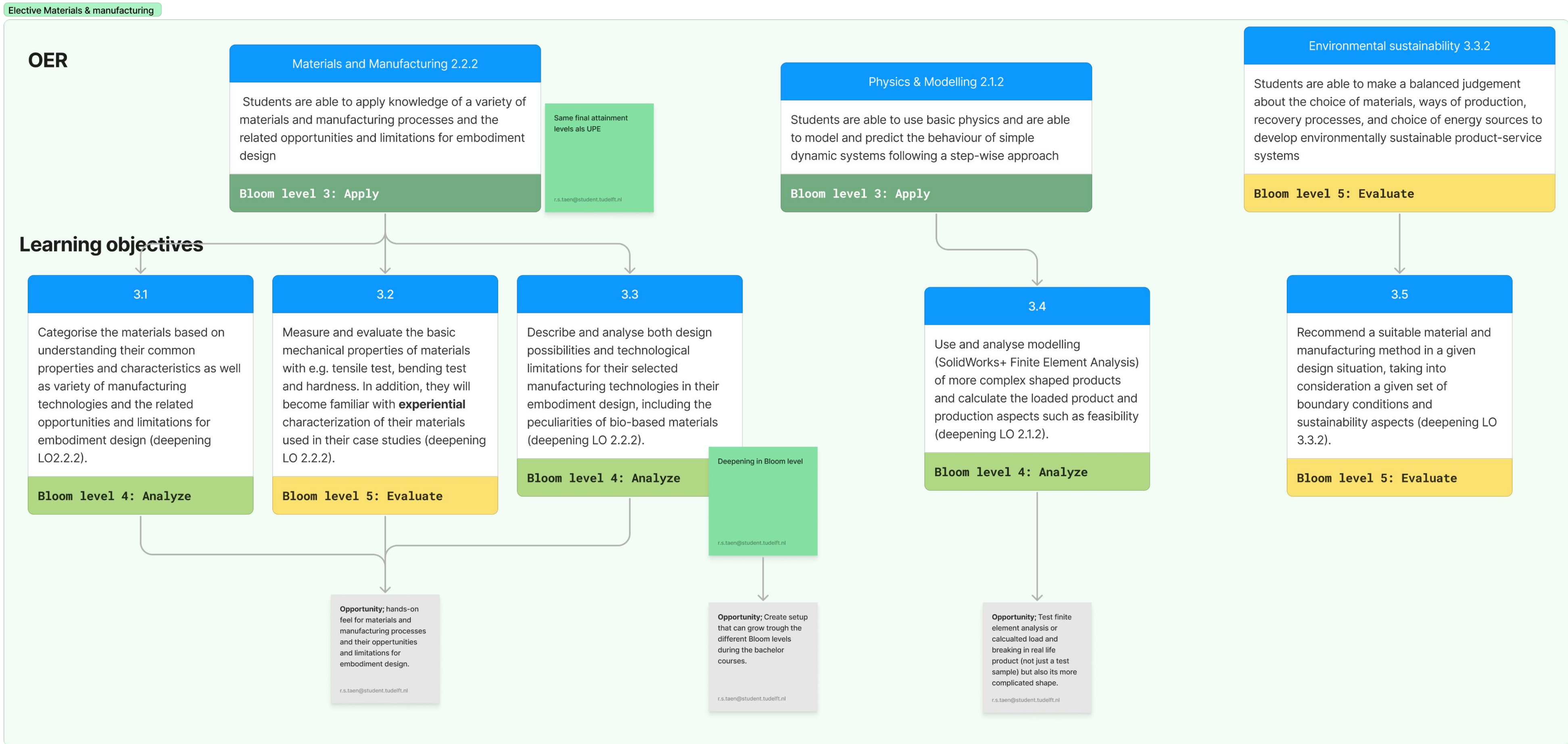
The course aims at equipping you with a wide range of advanced prototyping skills, techniques and materials to create prototypes, which capture both function and appearance of the intended design. To that aim, the course covers a broad interdisciplinary foundation, in-depth knowledge and practical skills, through (guest) lectures, hands-on workshops and multidisciplinary research/ design projects. In addition to the knowledge and skills necessary for building prototypes, the course injects necessary critical and creative thinking to determine which of these techniques and when in the design process could be applied, by considering desirability, feasibility, viability, as well as sustainability.

You will be able to:

- create prototypes that capture both function and appearance of the intended design
- think critical and creative to determine what techniques and when in the design process they could be applied
- consider desirability, feasibility, viability and sustainability

Appendix A.7 - M&M and AP course analysis

Materials & Manufacturing



Advanced prototyping

Minor Advanced prototyping

OER

Materials and Manufacturing 2.2.2	Architecture evaluation 2.5.1	Architecture specification 2.5.2	Environmental sustainability 3.3.2
Students are able to apply knowledge of a variety of materials and manufacturing processes and the related opportunities and limitations for embodiment design	Students are able to use analytical and experimental methods to test and evaluate functional and non-functional properties of a technical product/service architecture	Students are able to develop (alternative) architectures with respect to technical aspects	Students are able to make a balanced judgement about the choice of materials, ways of production, recovery processes, and choice of energy sources to develop environmentally sustainable product-service systems
Bloom level 3: Apply	**Bloom level 5: Evaluate**	**Bloom level 6: Create**	**Bloom level 5: Evaluate**

Appendix A.8 - Questionaire

Hoe wordt het weergegeven verpakkingsmateriaal geproduceerd?

Korte antwoordtekst

Dit is een holle speelgoed auto gemaakt van rood plastic.

Welk productie proces zou je hiervoor gebruiken?

Tekst lang antwoord

Wat betekent dit symbool dat op een beker staat? Waarom staat het erop?

Tekst lang antwoord

Bekijk de volgende barbecues.

Gegoten staal (cast iron) BBQ

Plaatstaal Aluminium BBQ

Plastic speelgoed BBQ

Je baas wilt 50 bbq's laten maken en verkopen als 'special product of the month'. Welk type BBQ is het goedkoopst en snelst om te laten maken? *

- Gegoten staal BBQ
- Plaatstaal Aluminium BBQ
- Plastic speelgoed BBQ

Welke BBQ vind jij het meest duurzaam en waarom?

Tekst lang antwoord

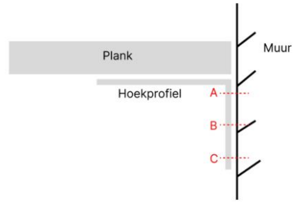
Van welk materiaal is deze mok gemaakt? *

Korte antwoordtekst

Je verwacht dat deze mok is gemaakt van Aluminium, hoe zou je dat testen en analyseren?

Korte antwoordtekst

Doormiddel van een hoekprofiel en 1 schroef, wil je een plankje bevestigen aan de muur. Op welke locatie zou je de schroef plaatsen?

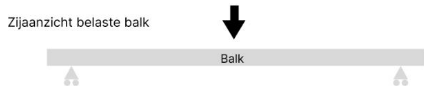


- A
- B
- C

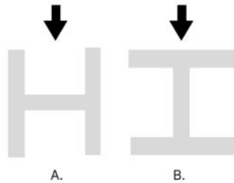
Waarom heb je voor deze plek gekozen?

Tekst lang antwoord

Bekijk deze situatie:



Dit is een dwarsdoorsnede van de balk die hierboven is afgebeeld. Welke oriëntatie heeft de hoogste weerstand tegen vervorming?

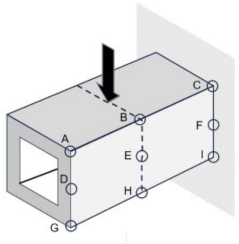


- Oriëntatie A
- Oriëntatie B
- Het maakt niet uit

Waarom stopt IKEA karton in hun tafelbladen?

Tekst lang antwoord

Een ingeklemde vierkante buis wordt belast met een kracht halverwege de balk. Door de kracht heersen er interne spanningen.



Geef hieronder aan wat voor soort spanning heerst in deze punten: trek, druk of geen spanning.

A

1. Trek
2. Druk
3. Geen spanning

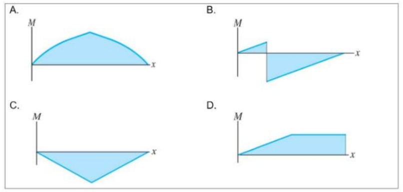
C

1. Trek
2. Druk
3. Geen spanning

F

1. Trek
2. Druk
3. Geen spanning

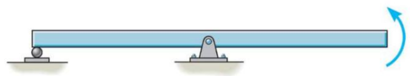
Welke buigmomentlijn hoort bij de bovenstaande situatie?



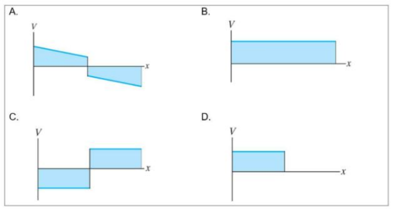
- A
- B
- C
- D

Bekijk de volgende situatie:

Gegeven de volgende belastingsituatie voor de ***volgende twee*** vragen.



Welke dwarskrachtlijn hoort bij bovenstaande situatie?



- A
- B
- C
- D

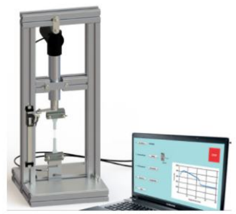
Van welk materiaal is het grootste deel van de buitenkant van deze auto gemaakt?

Korte antwoordtekst

Schat de dikte van dit materiaal in millimeters.

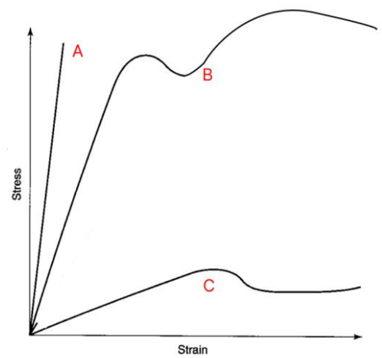
Korte antwoordtekst

Heb je de LETT trekbank wel eens gebruikt? Zo ja, wat vond je ervan?



Tekst lang antwoord

Dit zijn de resultaten van 3 verschillende lijnen. Je hebt Ceramic, Staal en Rubber getest. Welk materiaal behoort tot lijn B?



- Ceramic
- Rubber
- Staal

Algemene vragen

Beschrijving (optioneel)

In welk jaar IO zit je? *

Korte antwoordtekst

Kruis aan wat voor jou geldt.

- Ik heb nooit in de PMB gewerkt en het interesseert me ook niet
- Ik heb nooit in de PMB gewerkt, maar zou het wel graag doen
- Ik klus graag in de PMB
- Ik heb ervaring met de 3D printer en/of laser snijder
- Ik heb ervaring met de draaibank en/of frees
- Ik heb ervaring met de kantbank en/of CNC frees
- Anders...

Heb je het vak UPE (Understanding Product Engineering) gevolgd en succesvol afgerond? *

- Ja
- Nee
- Anders...

Kruis aan wat voor jou geldt *

- Ik heb geen fysieke prototypes gemaakt
- Ik heb alleen prototypes gemaakt voor visuele doeleinde
- Ik heb alleen prototypes gemaakt voor het testen van een technische werking
- Ik heb prototypes gemaakt voor het testen van beide doeleinde

Ben je tijdens je studie wel eens op bedrijfsbezoek geweest bij een fabriek? *

- Ja
- Nee

Waar op deze schaal zie je de bachelor IO? *

	1	2	3	4	5	6	7	8	9	10	
Theoretisch	○	○	○	○	○	○	○	○	○	○	Praktisch

Waar op deze schaal zou je de bachelor IO liever hebben? *

	1	2	3	4	5	6	7	8	9	10	
Theoretisch	○	○	○	○	○	○	○	○	○	○	Praktisch

Kruis aan welke onderdelen van UPE je het moeilijkst te begrijpen vond (maximaal 3).

- Basiswiskunde en vectoren
- Materialen (determinatie, emtalen, polymeren, dichtheid, recycling)
- Statica
- NVM lijnen (normaalkracht, dwarskracht, buigmoment)
- Spanning en vervorming
- Productie methodes
- Productopbouw en verbindingen
- Anders...

Waarom vond je de aangekruiste onderwerpen het ingewikkeldst?

Tekst lang antwoord

Hoe heb je de stof van UPE al in de realiteit toegepast?

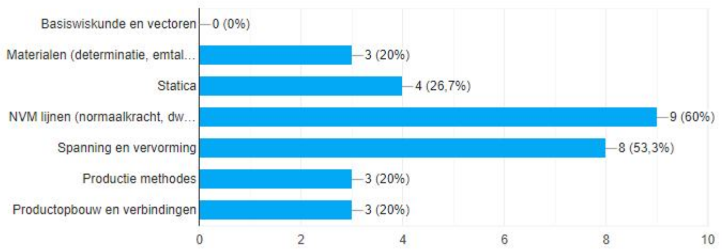
Tekst lang antwoord

Appendix A.9.1 - Questionaire Results

Kruis aan welke onderdelen van UPE je het moeilijkst te begrijpen vond (maximaal 3).

Kopiëren

15 antwoorden



De design project vakken worden vaak genoemd zoals DP1, dit betekent dat er wel enige aansluiting is tussen UPE en de werkelijkheid.

Maar er wordt ook wel gezegd dat het buiten die vakken niet echt gebruikt wordt nog, maar dat het wel tof zou zijn als dat kan.

Waarom vond je de aangekruiste onderwerpen het ingewikkeldst?
Onduidelijke uitleg, weinig oefenvragen
ent), Spanning en vervorming
De andere onderdelen zijn gemakkelijk te deduceren
Veel over verteld, maar weinig over laten zien in de praktijk
Dat was veel leren, ik ben beter in sommetjes en begrijpen
NVM & Spanning in eerste instantie, daarna snapte ik het wel. Productiemethodes omdat het er heel waren en je het niet echt toepast terwijl je er mee bezig bent.
Onduidelijk in uitleg, kort de tijd om 'eigen' te maken
Abstractie
Weinig tijd aan besteed
Spanning en vervorming: Aan veel dingen denken + afhankelijk van product en bv. moment of inertia enz. (Voor materialen/productiemethode enz vond ik het soms lastig inschatten wat bij een product past. Maar over het algemeen was dit niet super ingewikkeld)
Snap het niet
Ik snapte hier gewoon helemaal niks van
Omdat deze een toepassing waren op
Hier had ik nog weinig ervaring mee, en vond dat het beter uitgelegd kon worden in de coaching sessies.
Ik was er totaal niet in geïnteresseerd en verdiepte me er niet uit mezelf in.

Hoe heb je de stof van UPE al in de realiteit toegepast?
Keuze matieriaal tijdens dp1
Als ik zelf klus of 3d modelletjes maak denk ik vaak wel een de vervormingen en materialen
Nee, alleen bij een ander vak (PE en DP vakken)
1 of 2 keer bij een ontwerpvak
Misschien met hoe ik dingen recycle.
Toen ik het vak volgde en DP1 deed 1x per week ongeveer, nu amper
- Jump - Basiskennis waarom dingen kunnen falen
Nog niet exht
Statica is wel eens een aantal keer een beetje teruggekomen in een aantal andere vakken. Materialen en productiemethodes heb ik ook wel eens gebruikt maar andere stof heb ik nog vrij weinig toegepast.
Idk
Voor materiaal keuze en hoe sterk mijn product is
Ja bij m'n dp1 en dp2 project. Ik zou graag meer technische vakken willen zien.
Nog niet, maar dat zou wel echt tof zijn als je het kan toepassen in je leven.
Dp1
Vooral productietechnieken, maar niet technische uitwerking van producten

Heb je de LETT trekbank wel eens gebruikt? Zo ja, wat vond je ervan?
Ingewikkeld en onnauwkeurig
Nee
Nee
Ja, bij Materials & Manufacturing. Ik heb de data niet verwerkt, dus kan er niet veel over zeggen
Ja, iemand uit mijn groep voor materials & manufacturing, ik begreep er niet zo veel van, maar wel daarna de berekeningen met Solidworks
Nee
Ja, inklemming was slecht, stof scheurde. Instaleren van software was gedoe.
Ja leuk
Nee niet zelf, heb er wel eens een video van gezien
Ja, ik vond het wel cool
Ik vond het wel grappig om te zien hoe het werkt
Nee
Nee
Leerzaam
Ja, niet al te moeilijk maar soms onduidelijk om te lezen.
Niet zelf, alleen demonstratie, kon t daarom ook niet heel goed zien
ja half, ik heb hem gebruikt zien worden. maar een groepsgenoot deed het meeste werk. het was erg vermoeiend om de bouten steeds aan te draaien en de data eruit krijgen was soms erg lastig
Ja, met slecht materiaal faalt het bijna altijd bij de inklemming, waardoor waardes niet altijd accuraat zijn.
nee
Ja, makkelijk duurt wel lang om alles steeds vast te schroeven
Nooit gebruikt
Leuk, erg makkelijk. Kost alleen veel moeite om samples vast te maken (daar ben je vooral mee bezig).

Appendix A.9.2 - Questionaire Results

Q1.1 Results

Je baas wilt 50 BBQ's maken en verkopen als 'special product of the month' Welk type BBQ is het goedkoopst en snelst om te laten maken.

75%

25% snapt niet dat spuitgieten niet handig is voor 50 BBQ's

r.s.taen@student.tudelft.nl

Q1.2 Results

Welke BBQ vind jij het meest duurzaam en waarom?

22%

Really depends on the definition of sustainability however in general most answers to not go in depth.

r.s.taen@student.tudelft.nl

Q1.3 Results

Van welk materiaal is deze mok gemaakt

12.5%

Might not be enough hints but no basic feel

r.s.taen@student.tudelft.nl

Q1.4 Results

Je verwacht dat deze mok is gemaakt van Aluminium, hoe zou je dat testen en analyseren?

100%

All good results

r.s.taen@student.tudelft.nl

Welke BBQ vind jij het meest duurzaam en waarom?
Gehoten staal, sterk, lijkt het langst mee te gaan
Gegoten staal, gaat langer mee
De 2e, omdat die modulair lijkt, dus makkelijk onderdelen te vervangen
Aluminium, weinig materiaal nodig, uit standaard materiaal gemaakt en oneindig recyclebaar.
Gegoten staal want ik heb het gevoel dat die het langst meegaat
Gegegoten staal omdat je er het langst mee kan doen
De gegotenstaal BBQ is het meeste duurzaam door zijn lange levensduur, multifunctioneel, en betere kwaliteit. Plastic speelgoed BBQ is misschien niet duurzaam als je kijkt naar de impact op het milieu, maar er wordt wel veel waarde uitgehaald en lang worden gebruikt door de gebruikers.
Plastic is geen bbq
Plaatstaal aluminium heeft geen extra mal nodig en hoeft enkel uitgesneden (niet verhit) te worden.

Je verwacht dat deze mok is gemaakt van Aluminium, hoe zou je dat testen en analyseren?
Geleidbaarheid, gewicht, vormbaarheid
Wegen
Gewicht, buigbaarheid, magnetisme
Geleiding, en dichtheid
dichtheid meten
Gewicht en sterkte
Kijken of ie magnetisch is en dichtheid meten met water?
Aluminium is erg licht voor een metaal, ook is aluminium een goede geleider voor elektriciteit. Aluminium is niet magneetisch, dus ook zo kan je het teste
Gewicht
Volume met inhoud opmeten, buitenkant grootte berekenen en wegen. Dan vergelijken met bijv RVS en dan wat dichterbij zit.

Van welk materiaal is deze mok gemaakt?
Aluminium
Aluminum
Aluminium
Aluminium
Metaal - staal
Aluminium
Aluminium
Aluminium
Witgoud
Roestvrijstaal
keramiek met een zilveren verf
Aluminium
Aluminium
Staal
Rvs
Aluminium

Schat de dikte van dit materiaal in millimeters.
5
2
3mm
3mm
3 mm
5
0.5mm
5
3 mm
3mm
15 mm
50 mm
2.5 mm
1,2
6 mm

Q5.1 Results

Van welk materiaal is het grootste deel van de buitenkant van deze auto gemaakt?

43%

Als aluminium ook goed is bijna iedereen goed.

r.s.taen@student.tudelft.nl

Q5.2 Results

Schat de dikte van dit materiaal in millimeters.

6%

Dramatische antwoorden, totaal geen feeling

r.s.taen@student.tudelft.nl

Q5.3 Results

Heb je de LETT trekbank wel eens gebruikt? Zo ja, wat vond je ervan?

Mensen vinden het wel oke, maar niet laaiend enthousiast.

r.s.taen@student.tudelft.nl

Q5.3 Results

Dit zijn de resultaten van 3 verschillende lijnen. Je hebt Ceramic, Staal en Rubber getest. Welk materiaal behoort tot lijn B?

Werd goed begrepen

r.s.taen@student.tudelft.nl

Appendix A.9.3 - Questionnaire Results

Q2.1 Results

Doormiddel van een hoekprofiel en 1 schroef, wil je een plankje bevestigen aan de muur. Op welke locatie zou je de schroef plaatsen?

87.5

good results

r.s.taen@student.tudelft.nl

Q2.2 Results

Waarom heb je voor deze plek gekozen?

~50%

People can not properly explain it with the learned theory.

r.s.taen@student.tudelft.nl

Q2.3 Results

Dit is een dwarsdoorsnede van de balk die hierboven is afgebeeld. Welke oriëntatie heeft de hoogste weerstand tegen vervorming?

80%

Q2.4 Results

Waarom stopt IKEA karton in hun tafelbladen?

good results. Basic understanding

r.s.taen@student.tudelft.nl

Q3.1 Results

Hoe wordt het weergegeven verpakkingsmateriaal geproduceerd?

43%

Very low score for a relative easy question

r.s.taen@student.tudelft.nl

Q3.2 Results

Welk productie proces zou je hiervoor gebruiken?

30%

Very low score for a relative easy question

r.s.taen@student.tudelft.nl

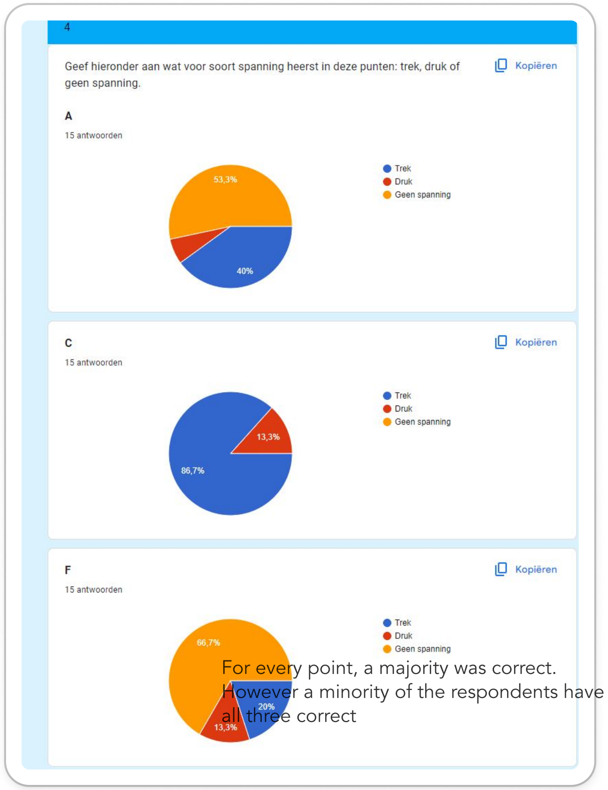
Q3.3 Results

Wat betekent dit symbool dat op een beker staat? Waarom staat het erop?

Wordt goed begrepen

r.s.taen@student.tudelft.nl

Waarom heb je voor deze plek gekozen?
Dichts bij plank, geen mogelijkheid om naar voren te kantelen
Dan is de arm helemaal bovenaan en houdt het profiel zich op de onderkant tegen de muur
is de arm het kortst dus sterker
Bij C zou de plank wel van de muur bewegen
Anders zou het iets meer naar links kantelen (moment?)
Moment = F * arm dus op deze plek is de meeste weerstand nodig
Omdat je hiermee zo'n klein mogelijk moment creëert
Daar is het momentum(?) grootst dus daar lekker stevig
Er staat hier minder stress op de schroef. Het moment op de plank is kleiner want afstand is kleiner.
Arm is het kleinst
Zo zie je die standaarden vaak gemonteerd
Omdat daar kleinste moment is
C is niet logisch omdat het hoekprofiel zich van de muur kan bewegen. Bij A en B heb je nog een deel van het hoekprofiel dat tegen de muur een kracht op oefent wat helpt met stabiliteit.
Krachtenspel
Anders krijg je de kans dat het hoekprofiel buigt.



For every point, a majority was correct. However a minority of the respondents have all three correct

Q4.1 Results

Welke spanning er heersen in de punten

40%

Q4.2 Results

Welke dwarskrachtlijn hoort bij de bovenstaande situatie

26.7%

Q4.3 Results

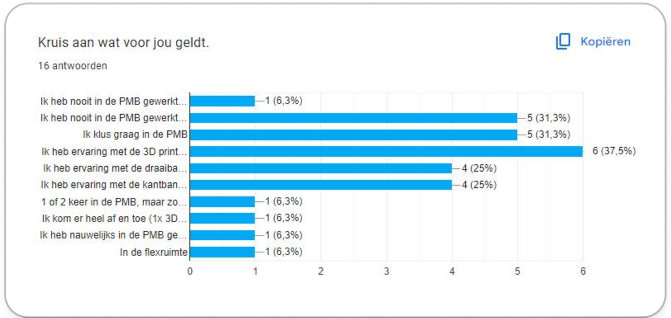
Welke buigmomentlijn hoort bij de bovenstaande situatie

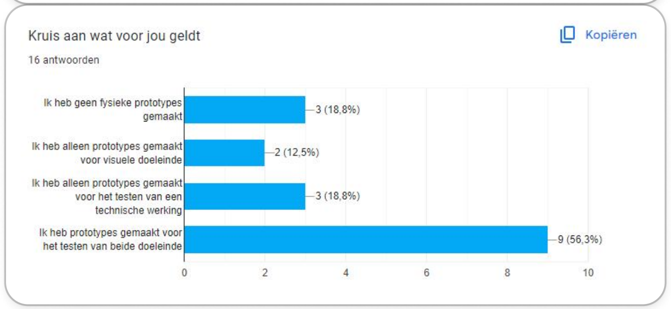
40%

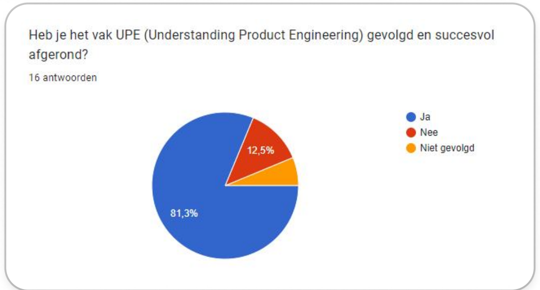
Most People cannot imagine it and understand it.

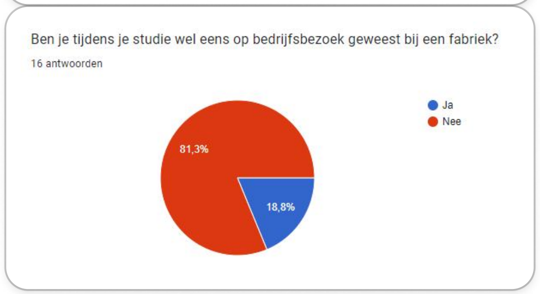
r.s.taen@student.tudelft.nl

Appendix A.9.4 - Questionnaire Results









Appendix A.10 - List of requirements Analysis

Value characteristics	Values	Creteria (wishes and requirements)- Analysis Phase
Desirability	dv-1 Facilitates experiential learning.	1. The workshop around the setup facilitates a form of external reflection.
		2. Students need to be actively involved in using the setup. This means they have to use their senses and interact with it to get results.
	dv-2 Adaptable to courses with a productive failure approach	3. The setup can serve as a standalone educational tool or as part of a productive failure workshop.
	dv-3 User-friendly design	4. >80% should be able to use the setup without a manual.
		5. The time to setup the setup should be smaller than using the setup.
		6. The setup should be accessible from all sides.
	dv- 4 Exciting design	-
	dv-5 Accessible design	6. The setup should be accessible from all sides.
		7. The setup should be able to be used by other faculties and therefore online displayed.
		8. The setup should be visible in the current daily workday of a student.
		9. Missing parts have to be discovered before using the setup.
Feasibility	fv-2 Safe design	13. CE-certified (safety standard)
	fv-7 Integration in IDE education	15. 350 Students can experience the setup in one afternoon (4 hours).
		14. To make the setup applicable for several courses it should educate on different bloom levels.
		12. Keep cost low (later on define price minimum)
	fv-8 Portability and storage	20. Make it easy to store, and relocate
Viabilty	vv -1 Low investment costs	12. Keep cost low (later on define price minimum)
	vv- 2 Low maintenance	9. Missing parts have to be discovered before using the setup.
		10. Low parts cost (later define the price)
	vv-3 High return of investment	11. The setup should be versatile and educate students with different engineering principles
		18. The setup is multi-functional
	vv-4 Versatile and Scalability	14. To make the setup applicable for several courses it should educate on different bloom levels.
	vv-5 Enhances education results	~~16. The setup should educate on the subject product structure.~~
		17. The setup should educate on the Manufacturing methods and materials
		~~18. The setup should educate on the subject NVM lines, forces and deflection.~~

Appendix B.1 - List of requirements v1

Value characteristics	Values	Creteria (wishes and requirements)- Analysis Phase	Creteria V1
Desirability	dv-1 Facilitates experiential learning.	1. The workshop around the setup facilitates a form of external reflection.	
		2. Students need to be actively involved in using the setup. This means they have to use their senses and interact with it to get results.	
	dv-2 Adaptable to courses with a productive failure approach	3. The setup can serve as a standalone educational tool or as part of a productive failure workshop.	
	dv-3 User-friendly design	4. >80% should be able to use the setup without a manual.	
		5. The time to setup the setup should be smaller than using the setup.	
		6. The setup should be accessible from all sides.	
	dv- 4 Exciting design	- insights	
	dv-5 Accessible design	6. The setup should be accessible from all sides.	
		7. The setup should be able to be used by other faculties and therefore online displayed.	
		8. The setup should be visible in the current daily workday of a student.	
		9. Missing parts have to be discovered before using the setup.	
	dv-6 Intruiging design	- insights	
	dv-8 Educational setup Appeal		24. The setup should have a robust and sturdy feel.
			26. Use premium materials
Feasibility	fv-1 Making real products/parts		21. The prototype makes real products/parts
	fv-2 Safe design	13. CE-certified (safety standard)	
	fv-3 Working prototype (TRL 7-Prototype demonstration in operational environment)		- insight
	fv-4 Production ready		- insight
	fv-5 Cost estimate is known		
	fv-6 User tested		
	fv-7 Integration in IDE education	15. 350 Students can experience the setup in one afternoon (4 hours).	
		14. To make the setup applicable for several courses it should educate on different bloom levels.	
		12. Keep cost low (later on define price minimum)	
	fv-8 Portability and storage	20. Make it easy to store, and relocate	
Viabilty	vv -1 Low investment costs	12. Keep cost low (later on define price minimum)	12. Keep cost for one configuration €150
	vv- 2 Low maintenance	9. Missing parts have to be discovered before using the setup.	
		10. Low parts cost (later define the price)	
	vv-3 High return of investment	11. The setup should be versatile and educate students with different engineering principles	
		18. The setup is multi-functional	
	vv-4 Versatile and Scalability	14. To make the setup applicable for several courses it should educate on different bloom levels.	14. The setup should educate on different bloom levels.
	vv-5 Enhances education results	~~16. The setup should educate on the subject product structure.~~	Out of scope
		17. The setup should educate on the Manufacturing methods and materials	17. The setup should educate on the Manufacturing methods and materials and its oppertunities and limitations.
			23. The vacuum former configuration should use a manual heating gun.
			25. The setup should have the same (but smaller) limitations as professional machines to discover design requirements.
			22. The vacuum former configuration should allow different molds to be used.
		~~18. The setup should educate on the subject NVM lines, forces and deflection.~~	Out of scope
	vv-6 Different focus than market alternatives		12. Keep cost low (later on define price minimum)

Appendix B.1 - Consent form

Informed consent form: Experiential Machines for Industrial Design Engineering students

This research is conducted as part of the MSc Industrial Design Engineering Theses at the TU Delft

Researcher; Robin Taen
Contact;

The purpose of this research study is to evaluate the effectiveness and understanding of experiential machines, and will take you approximately 15 minutes to complete. The data will be used for Robin's master theses. It will be published in the public Tu Delft repository, and potentially be used for teaching purposes. I will be asking you to complete certain tasks for which you have to engage with the experiential machines.

To the best of my ability your answers and action in this study will remain confidential. I will minimize any risks by keeping all your personal information anonymous. During the test you will be video recorded. Depending on your preference faces can be blurred and anonymized.

Informed consent participant

I acknowledge that I received sufficient information and explanation about the research and that all my questions have been answered satisfactorily. I was given sufficient time to consent my participation. I can ask questions for further clarification at any moment during the research.

I am aware that this research consists of the following activities:

1. Test the experiential setup
2. Short interview

I am aware that data will be collected during the research, such as notes, photos, video and/or audio recordings. I give permission for collecting this data and for making photos, audio and/or video recordings during the research. Data will be processed and analysed anonymously (without your name or other Identifiable Information). The data will only be accessible for the researcher.

The photos, video and/or audio recordings will be used to support analysis of the collected data. The video recordings and photos can also be used to illustrate research findings in publications and presentations about the project.

I give permission for using photos and/or video recordings of my participation:
(select what applies for you)

☐ **in which <u>I am recognisable</u> in publications and presentations about the project.**

☐ **in which I <u>am not recognisable</u> in publications and presentations about the project.**

☐ **<u>I do not give permission</u>, for data analysis only and not for publications and presentations about the project.**

With my signature I acknowledge that I have read the provided information about the research and understand the nature of my participation. I understand that I am free to withdraw and stop participation in the research at any given time. I understand that I am not obliged to answer questions which I prefer not to answer and I can indicate this to the researcher

______________	______________	______________
Participant name	**Signature**	**Date**

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

______________	______________	______________
Researcher name	Signature	Date

Appendix B.2 - Knowladge test

Welk productie proces is hier gebruikt?

Heb je dit productie proces zelf (in de PMB) gebruikt?

Noem 3 dingen waar een ontwerper op moet letten bij het ontwerpen van een product/ onderdeel die met dit productie proces gefabriceerd wordt?

Welk materiaal wordt er gebruikt voor dit productie proces?

Wat schat je dat de dikte is van dit materiaal?

Appendix B.3.1 - HREC device report

Delft University of Technology
INSPECTION REPORT FOR DEVICES TO BE USED IN CONNECTION WITH HUMAN SUBJECT RESEARCH

This report should be completed for every experimental device that is to be used in interaction with humans and that is not CE certified or used in a setting where the CE certification no longer applies[1].

The first part of the report has to be completed by the researcher and/or a responsible technician.

Then, the safety officer (Heath, Security and Environment advisor) of the faculty responsible for the device has to inspect the device and fill in the second part of this form. An actual list of safety-officers is provided on this webpage.

Note that in addition to this, all experiments that involve human subjects have to be approved by the Human Research Ethics Committee of TU Delft. Information on ethics topics, including the application process, is provided on the HREC website.

Device identification (name, location): Experiential Machine v2, TU Delft, MSc Thesis

Configurations inspected[2]: 3

Type of experiment to be carried out on the device:[3] Vacuum forming, Metal bending, Injection moulding

Name(s) of applicants(s): Dr.ir. S.F.J. (Bas) Flipsen

Job title(s) of applicants(s): TU Delft employee

(Please note that the inspection report should be filled in by a TU Delft employee. In case of a BSc/MSc thesis project, the responsible supervisor has to fill in and sign the inspection report.)

Date: 30-4-2024

Signature(s):

1 Modified, altered, used for a purpose not reasonably foreseen in the CE certification

2 If the devices can be used in multiple configurations, otherwise insert NA

3 e.g. driving, flying, VR navigation, physical exercise, ...

Setup summary

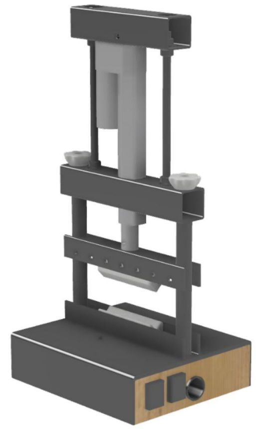
Please provide a brief description of the experimental device (functions and components) and the setup in which context it supposed to be used. Please document with pictures where necessary.

More elaborate descriptions should be added as an appendix (see below).

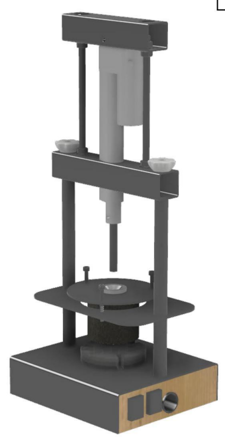
The experimental device is and experiential machine that can be configured in 3 different ways. Each creating a miniature production machine. The goal of the machine is to get familiar with manufacturing process and materials.

The three configurations;

Vacuum forming



Metal forming



Injection moulding

Appendix B.3.2 - HREC device report

Risk checklist

Please fill in the following checklist and consider these hazards that are typically present in many research setups. If a hazard is present, please describe how it is dealt with.

Also, mention any other hazards that are present.

Hazard type	Present	Hazard source	Mitigation measures
Mechanical (sharp edges, moving equipment, etc.)	Metal forming, Plastic injection.	Cut finger, crush finger	Deburred all sharp edges. Careful explanation what part will move. Only when button is pressed. Actuator moves. Slow speed of actuator. Max force of 100kg.
Electrical	All	Electric shock/Electrocution 230v	Use 12V for linear actuator CE-certified converter 230V to 12V. Special screw to open 230 V components Ground wires to chassis. Use proper cable connections. Use C13 Device cable for 230v AC and xt60H for 12V DC connection.
Structural failure			
Touch Temperature	Injection moulding, vacuum forming	Burning finger or hand	Careful explanation what parts get hot. Injection moulding; Shielding the hot parts with insulation and protective cover. Vacuum forming ; Heating is done by a CE-certified machine, a heat gun.
Electromagnetic radiation			
Ionizing radiation			
(Near-)optical radiation (lasers, IR-, UV-, bright visible light sources)			
Noise exposure			
Materials (flammability, offgassing, etc.)			
Chemical processes			
Fall risk			
Other:			

Appendices

Here, you may add one or more appendices describing more detailed aspects of your setup or the research procedures.

Vacuum forming

Possible risks,

Touch temperature.

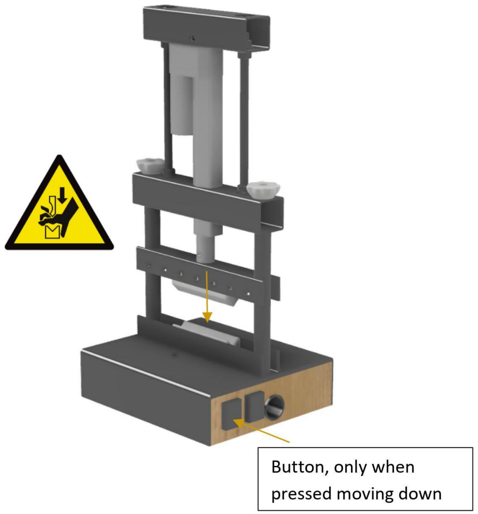
Heating is done by a CE-certified machine, a heat gun.

Electrical.

Professional plugs and sockets are used and all connections are inaccessible

Appendix B.3.3 - HREC device report

Metal forming



Possible risks,

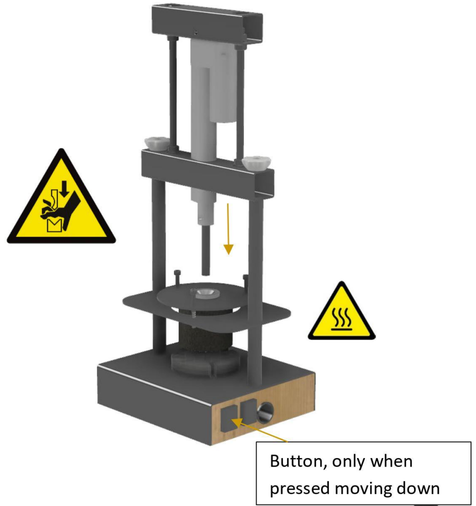
Mechanical

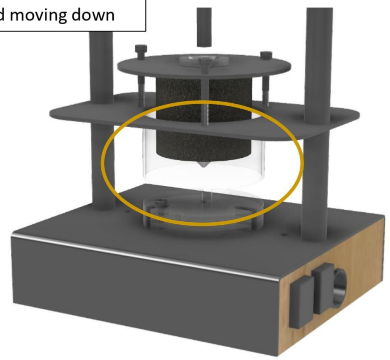
Deburred all sharp edges.
Careful explanation what part will move.
Only when button is pressed. Actuator moves.
Slow speed of actuator.
Max force of 100kg.

Electrical.

Professional plugs and sockets are used and all connections are inaccessible

Injection moulding





Possible risks,

Mechanical

Deburred all sharp edges.
Careful explanation what part will move.
Only when button is pressed. Actuator moves.
Slow speed of actuator.
Max force of 100kg.

Electrical.

Professional plugs and sockets are used and all connections are inaccessible

Touch temperature.

Careful explanation what parts get hot.
Injection moulding; Shielding the hot parts with insulation and protective cover.

Appendix B.3.4 - HREC device report

Device inspection
(to be filled in by the AMA advisor of the corresponding faculty)
Name:

Faculty: Master Theses and therefore checked by project supervisor, see first page

The device and its surroundings described above have been inspected. During this inspection I could not detect any extraordinary risks.

(Briefly describe what components have been inspected and to what extent (i.e. visually, mechanical testing, measurements for electrical safety etc.)

Date: Master theses and therefore checked by project supervisor, see first page

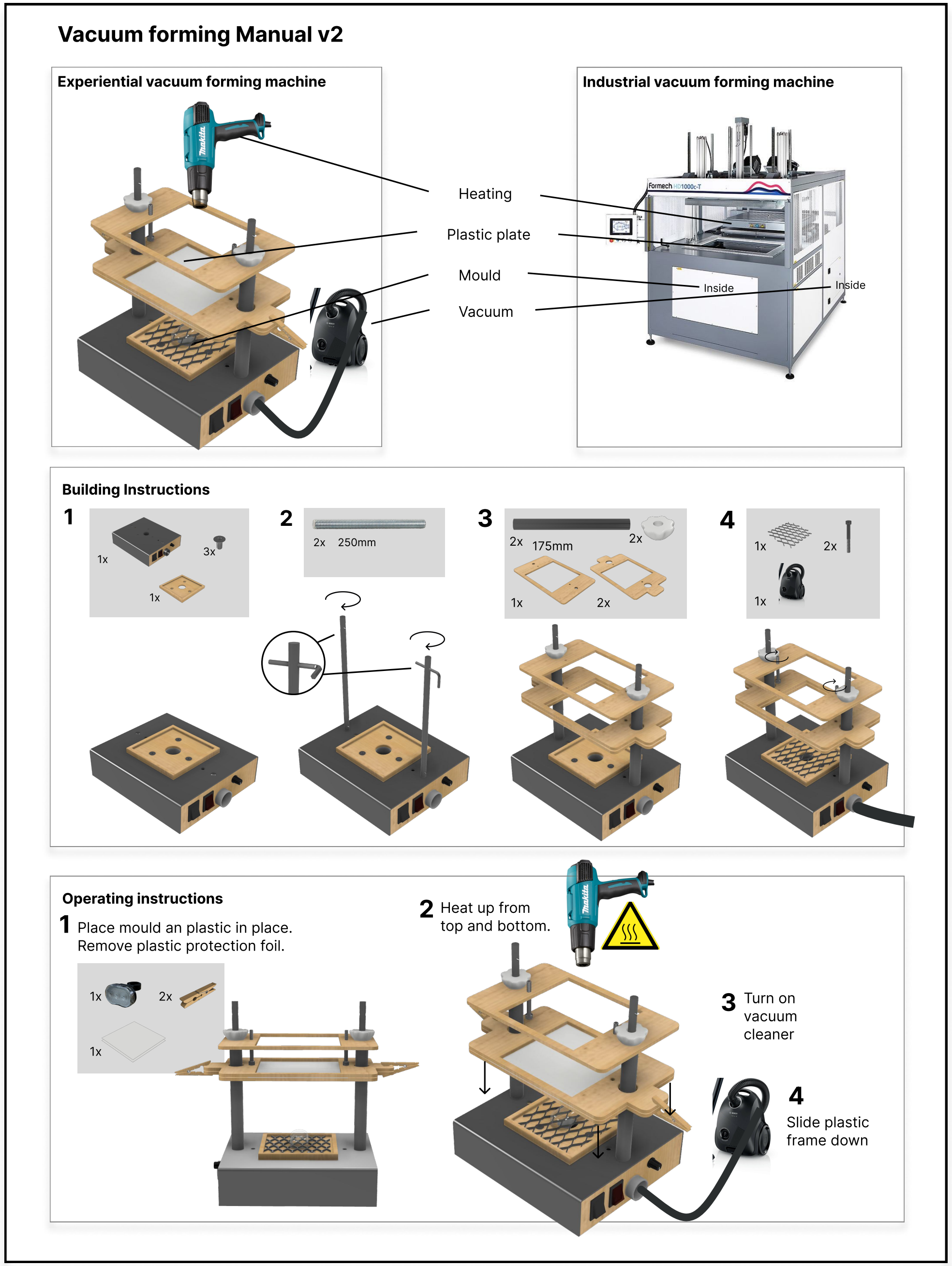
Signature:

Inspection valid until[4]:

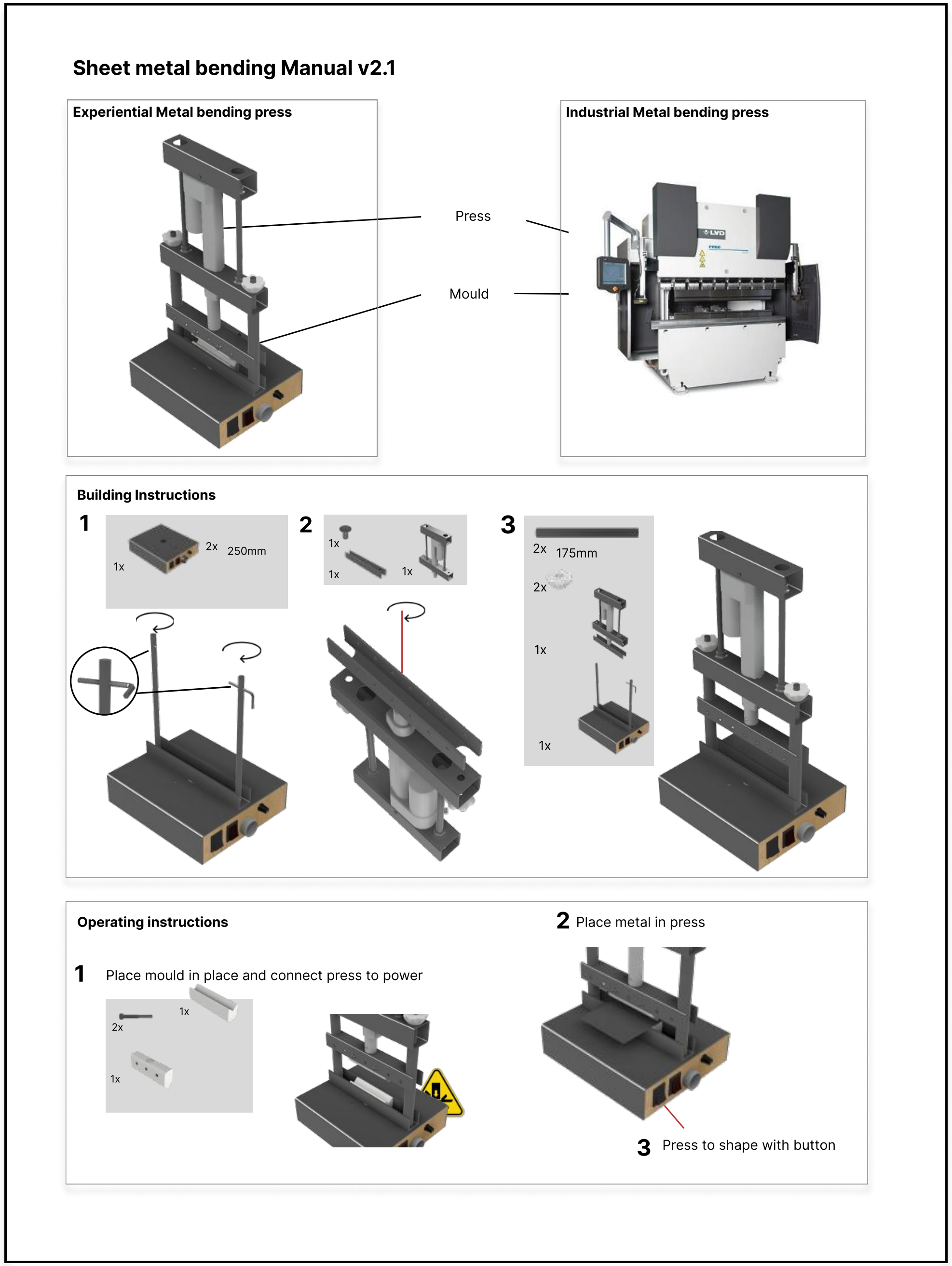
Note: changes to the device or set-up, or use of the device for an experiment type that it was not inspected for require a renewed inspection

4 Indicate validity of the inspection, with a maximum of 3 years

Appendix B.4.1 - Manual



Inspiration from; (Building Instructions - Customer Service - LEGO.com US, n.d.)

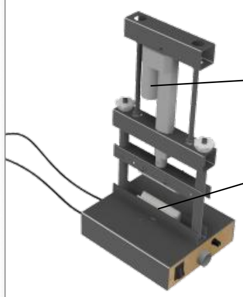


Inspiration from; (Building Instructions - Customer Service - LEGO.com US, n.d.)

Appendix B.4.2 - Manual

Sheet metal bending Manual v2.2

Experiential Metal bending press

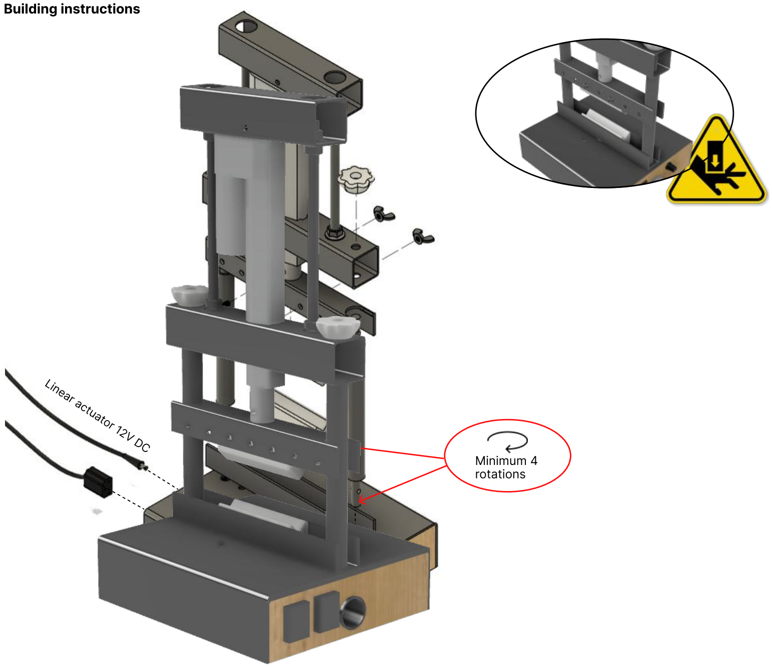


Press

Mould

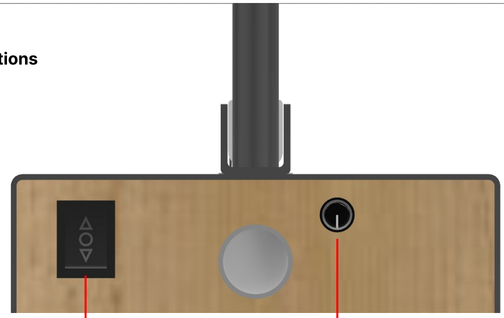
Industrial Metal bending press

Building instructions



Iteration to exploded view.

1 Operating instructions



Up-Down

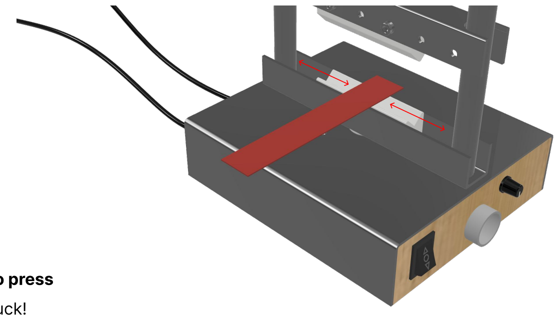
When motor stops, do not keep pressing. Then the motor will break.

Speed

Low = No movement & Lower force
High = Fast movement & More force

2 Place sheet material in press

Place metal in the centre. This prevents the linear actuator from breaking

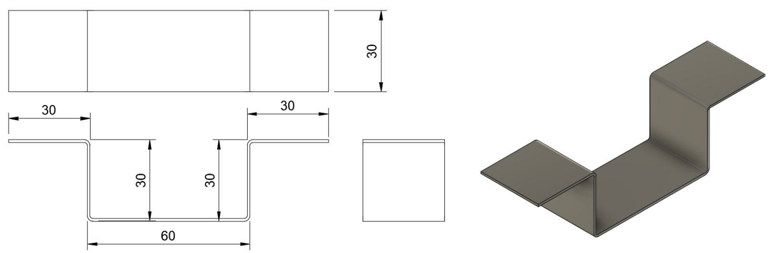


3 Time to press

Good luck!

Drawings

Handle



Appendix B.5.1 - DEVAN analysis

Time code	Time taken	Breakdown indication code (user product interaction)	free form decription	Comments by participants	Context	Emotion	Eduction	Improvement
0:00	0	EDU	analyses the componetns			Excited	Learns that there is a protective foil on sheet	
0:27	0:27		connects pillars			confident		
1:23	0:56	READ	read manual					
1:35	0:12	ACT	order wrong. does not see nuts in description. wants arrow on manual					
1:54	0:19		screwing tight base plate			annoyed		
3:11	1:17	READ						
3:15	0:04	SEARCH	connect tubes					
3:26	0:11		fastens screws more					
3:56	0:30			I would not look so quickly to building insturctions. There is standing 1,2,3,4. but would like to figure it out myself.	Building machine			
4:17	0:21		Connect frame					
4:25	0:08	SEARCH		Where this is for no clue				Remove top frame vacuum former. no function
4:26	0:01		connects nuts					
4:35	0:09		gasje					
4:44	0:09		Vacuum cleaner					
5:12	0:28			Difficult to see the difference between the images				
5:13	0:01	SEARCH						Make clear what parts you need to use
5:18	0:05		fidgiting with plastic and wasknijper					remove wasknijper system and easier to put plastic in
Assembly time	**5:18**							
5:18								
6:06	0:48	PUZZLED	Wonderinng what the task is	Do i want to design packaging?		unsure		
6:20	0:14		fidgiting with plastic and wasknijper					
7:40	1:20	EDU		Removes plastic foil			Learns that there is a protective foil on sheet	
8:25	0:45	EDU	mould orientation			Unsure	Wondering about mould orientation up or down	
8:36	0:11	READ			Making product try 1			
8:45	0:09		Starts heating					
10:12	1:27		Stops heating and turn on vacuum					
10:18	0:06	EDU	Slides down frame (does not hold on handles)			Dissapointed	No vacuum, it does not work	(does not hold on handles)
10:53	0:35	EDU	takes out frame			Happy	Feels how warm it is.	
11:21	0:28		done					
Manufacturing time	**6:15**							
0:00	0:00	EDU	removes protection foil			Confident	Learns about different colours plastic	
0:09	0:09	ACT	places protection foil wrong place					
0:23	0:14	REC	puts it in right place					connect wasknijpers in wrong place
0:50	0:27		starts heating		Making product try 2			
1:39	0:49		Stops heating			Confident		
1:39	0:00		turns on vacuum cleaner					
1:44	0:05		heating again					vacuum while heating
1:55	0:11		slides down frame, and appreciates			Happy, amazed		
2:08	0:13		takes out plastic					
2:30	0:22		Done					
Manufacturing time	**2:15**							

Appendix B.5.2 - DEVAN analysis

	Breakdown indication code (user product interaction)	free form decription	Comments by participants	Context	Emotion	Eduction
0		analysing the surrounding	Reading, I wouldn't do that.			
0:14		stand up posts				
0:17	READ	reading				
0:10		connecting base plate				
2:11		tightening stand up posts				
0:16		Connects cilinders				
0:12		Connects frame		Building machine		
0:22	ACT	connects nuts (forgets top frame				
0:11	CORR	corrects				
0:45	READ	Read				
0:20		Finishes design				
1:52		Checks design				
0:19		Building finished				
7:09						
		Connects heaters				
0:18	READ					
0:08	EDU	dry run				Conducts a dry run to analyse how it works
0:15	EDU					Feels the heat with his hands
0:36		Turns on vacuum				
0:06		slides down frame		Making product try 1		
0:07	EDU	Does nog vacuum form	Should be much warmer			Learns what tempratures the plastic is.
0:10	DSF	reheats				overheats plastic not properly aligned
1:44		Slides down again	No vacuum		Dissapointe	Does not completly understand why
0:26	SEARCH		The turning button does nothing? Does it?			Wonders if the turning button does somethin
3:55						
		Heats up				
0:59		Feels plastic for first time				Feels the plastic
0:21		Feels plastic again		Making product try 2		Feels plastic again
0:17		Slides down. proper vacuum	eyyy		Excited	
0:09		Feels plastic again for turning of vacuum				Feels plastic agian before turning off vacuum
0:44			This went much better!			REalises that it cools down very quickly
2:30						

Appendix B.5.3 - DEVAN analysis

Vacuum 2.3	Aware of plastic vacuu	Beachalor						
Time code	**Time taken**	**Breakdown indication code (user product interaction)**	**free form decription**	**Comments by participants**	**Context**	**Emotion**	**Eduction**	**Improvement**
0:00	0		placing central plate and screwing it together					
1:19	1:19		connect pillars					change that you have to screw it in with your hands
2:00	0:41	ACT	connecting tubes					
2:23	0:23	CORR	tightening pillars					
2:43	0:20		Adds mesh					
2:47	0:04		connects frame+plastic		Building machine			
4:27	1:40	READ	reads			Puzzled		
4:40	0:13			ahhhh			Understand how the design works	
5:30	0:50		Wasknijpers	iets anders dan wasnijpers				remove wasknijpers
6:02	0:32	CORR	removes plastic film				learns that there is a plastic film on the plastic	
7:32	1:30		Done					
Assembly time	**7:32**							
7:32				How do I know when the plastic is hot enough?				
7:49	0:17		Starts heating					
8:29	0:40		Turns of vacuum while heating					
8:32	0:03		slides it down		Making product try 1	content	He realises that it could be warmer, not enough power he thinks. Directly starts analysing	
9:25	0:53						Students joins to look	
9:32	0:07						autonomosly starts a reflection. Would like to implement in in a project	
12:00	2:28		Done					
Manufacturing time	**1:00**							

Appendix B.5.4 - DEVAN analysis

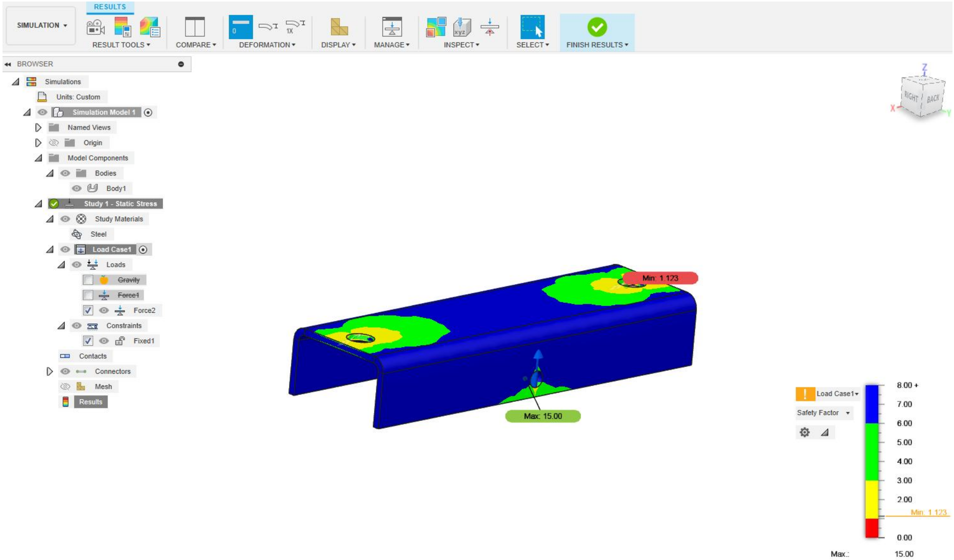
Time code	Time taken	Breakdown indication code (user product interaction)	free form decription	Comments by participants	Context	Emotion	Eduction	Improvement
0:00	0	READ	analyse all parts	Reading, I wouldn't do that.				
1:06	1:06		adds base plate					
1:20	0:14			Did not get the manual stepps. too small				Change manual form
1:40	0:20		tightens the screws					
2:50	1:10		Connects pillars					
3:46	0:56		add tubes	no clue why that would be nessecairy				
3:57	0:11	READ			Building machine			
4:09	0:12		Adds frames					
5:00	0:51		Adds nuts			Satisfaction with hand twisting nuts		
5:50	0:50		Handeling the plastic					
6:20	0:30	Search		How does it stay up				
6:25	0:05		Discovers magnets					
8:12	1:47		Setup finished					
Assembly time	**8:12**							
8:12		EDU	starts heating				Discovers that it doesnt deform with too little heat	
8:44	0:32		slides down					
9:00	0:16		heats again			curious		
9:01	0:01		heats again			unsure		
10:17	1:16	EDU	slides down again	Why should it be quick?	Making product try 1		Does not get why you have to be quick	
	13:43	EDU	Forgets to connect vacuum cleaner				realized you have to turn on the vacuum former, and why it is called vacuum forming.	
11:26	11:26	EDU	takes it out			sattisfied		
11:36	0:10			"best leuk!"				
Manufacturing time	**3:16**							
0:00			takes of plastic					
0:20	0:20		Places plastic in frame					
0:55	0:35		heats up		Making product try 2			
2:09	1:14			sick		Super excited and suprised		
2:20	0:11	EDU				Does not comple	Does not completely pull vacuum on the sides, questions herselve it it isnt hot enough thten?	
Manufacturing time	**2:30**							

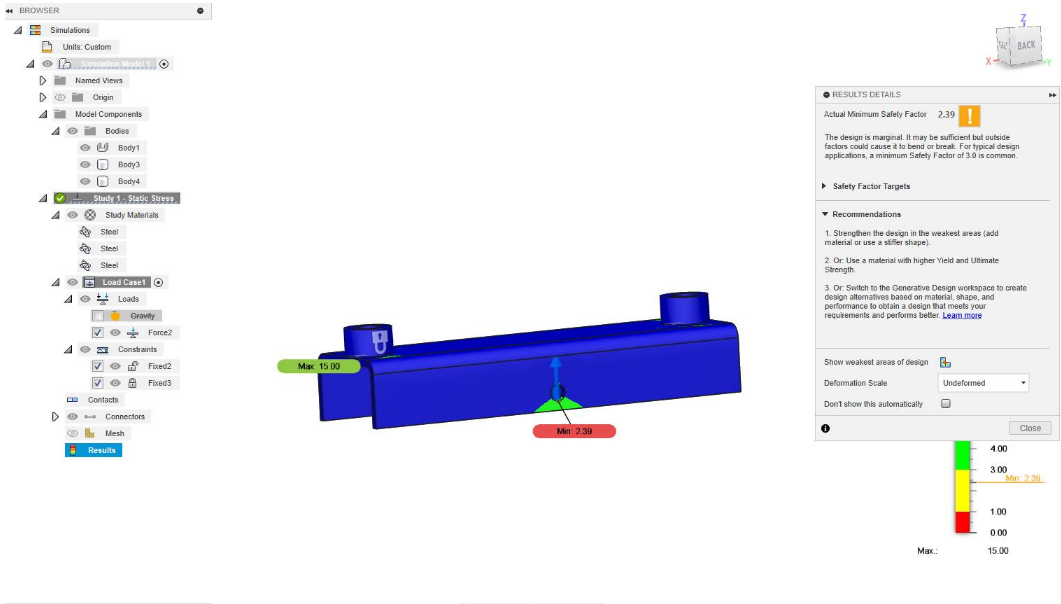
Appendix B.5.4 - DEVAN analysis

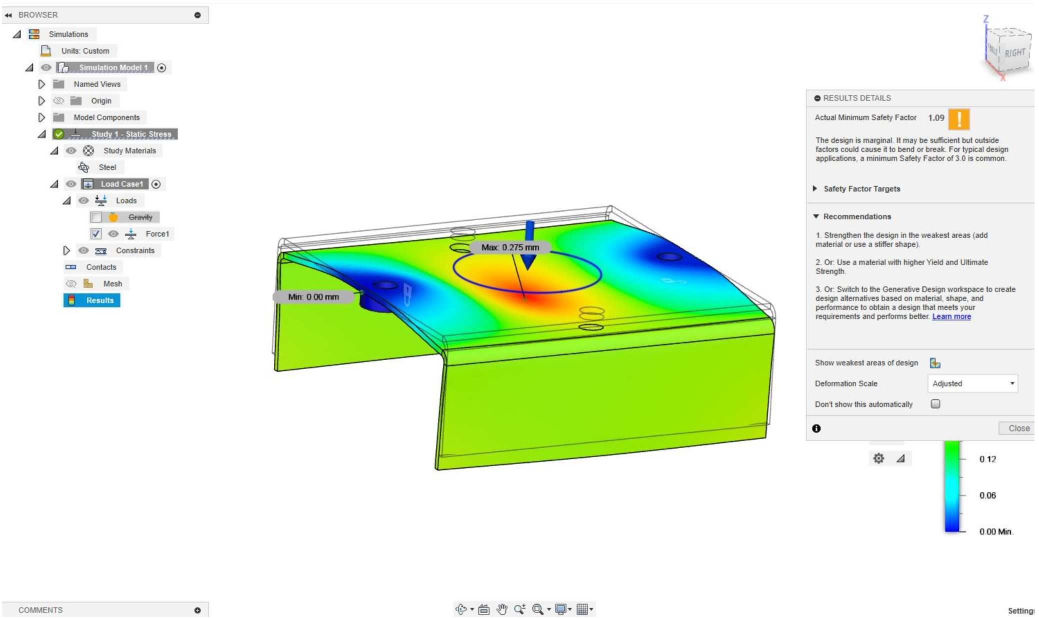
Time code	Time taken	Breakdown indication code (user product interaction)	free form decription	Comments by participants	Context	Emotion	Eduction	Improvement
0:00	0	READ	analyse all parts	Reading, I wouldn't do that.	Building machine			
1:06	1:06		adds base plate					
1:20	0:14			Did not get the manual stepps. too small				Change manual form
1:40	0:20		tightens the screws					
2:50	1:10		Connects pillars					
3:46	0:56		add tubes	no clue why that would be nessecairy				
3:57	0:11	READ						
4:09	0:12		Adds frames					
5:00	0:51		Adds nuts			Satisfaction with hand twisting nuts		
5:50	0:50		Handeling the plastic					
6:20	0:30	Search		How does it stay up				
6:25	0:05		Discovers magnets					
8:12	1:47		Setup finished					
Assembly time	**8:12**							
8:12		EDU	starts heating		Making product try 1		Discovers that it doesnt deform with too little heat	
8:44	0:32		slides down					
9:00	0:16		heats again			curious		
9:01	0:01		heats again			unsure		
10:17	1:16	EDU	slides down again	Why should it be quick?			Does not get why you have to be quick	
	13:43	EDU	Forgets to connect vacuum cleaner				realized you have to turn on the vacuum former, and why it is called vacuum forming.	
11:26	11:26	EDU	takes it out			satisfied		
11:36	0:10			"best leuk!"				
Manufacturing time	**3:16**							
0:00			takes of plastic		Making product try 2			
0:20	0:20		Places plastic in frame					
0:55	0:35		heats up					
2:09	1:14			sick		Super excited and suprised		
2:20	0:11	EDU				Does not comple	Does not completely pull vacuum on the sides, questions herselve it it isnt hot enough thten?	
Manufacturing time	**2:30**							

Appendix B.6 Simulations

To determine the right metal thickness and shape.







Wat een lang verslag he. Tijd voor een kleine lunch pauze?;

BENODIGDHEDEN

- 2 eieren
- 250 gr bloem
- 500 ml melk
- zout

BEREIDINGSWIJZE

1. Meng in een kom de eieren, de bloem, melk en een snufje zout met een garde of elektrische mixer. Als alle klontjes zijn verdwenen, kunnen de pannenkoeken gebakken worden. 2.Verwarm een beetje boter, margarine of olie in een koekenpan. Wacht even totdat de pan goed warm is, en verdeel dan met een soeplepel wat beslag in het midden van de pan. Beweeg je pan een beetje heen en weer zodat het beslag over de hele pan verdeeld is. 3. Bak de pannenkoek ongeveer 2-3 minuten totdat de bovenkant droog is. Draai de pannenkoek om en bak de pannenkoek nog ongeveer 1-2 minuten op de andere kant. 4. Leg de pannenkoek op een bord en dek het bord af met een grote deksel. Bak zo de rest van de pannenkoeken. 5. Vergeet niet om iedere keer een beetje extra boter of olie in de pan te doen, voordat je een nieuwe pannenkoek bakt.

Appendix B.7 Metal bending machines

Industry

(Harsle press - n.d)

(Press brake industrial - n.d)

(Press brake industrial 2 - n.d)

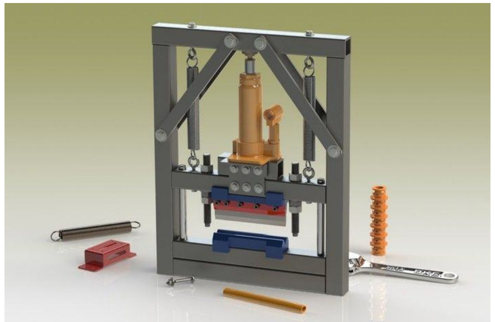
Workshop

(Hydraulic Bending Press Machine for Sheet Metal, n.d.)

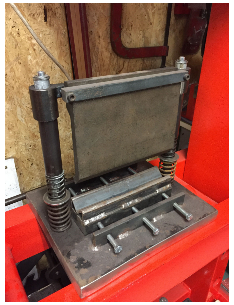
(W.415WBA | Facom 15t Hydraulic Press | RS, n.d.)

(Amazon.com: KASTFORCE KF5017 Press Brake Attachment, n.d.)

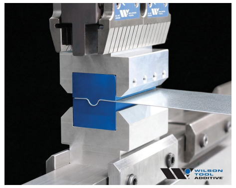
Hobby



(Sheet-Metal Mini Workshop Press Brake – STL, STEP, n.d.)



(Press brake hobby - n.d)



(Additive Tech Takes on Short-run Press Brake Tooling, n.d.)

W.415WBA | Facom 15t Hydraulic Press | RS. (n.d.). https://www.google.com/imgres?imgurl=https://res.cloudinary.com/rsc/image/upload/b_rgb:FFFFFF,c_pad,dpr_2.625,f_auto,h_214,q_auto,w_380/c_pad,h_214,w_380/Y2357093-01?pgw%3D1&tbnid=dRf8rnKcKibQAM&vet=1&imgrefurl=https://nl.rs-online.com/web/p/machine-presses/2357093&docid=XcEFQgdQzyKR8M&w=998&h=562&source=sh/x/im/m1/1&kgs=997028f3a300410a&shem=abme,trie

Amazon.com: KASTFORCE KF5017 Press Brake Attachment. (n.d.). https://www.google.com/imgres?imgurl=https%3A%2F%2Fm.media-amazon.com%2Fimages%2FI%2F71wxNZPeS1L.jpg&tbnid=2jIS_YbXgnfNbM&vet=1&imgrefurl=https%3A%2F%2Fwww.amazon.com%2FKASTFORCE-KF5017-Attachment-Standard-Hydraulic%2Fdp%2FB0BXNB5FQJ&docid=ciku4sngr387VM&w=2500&h=2500&source=sh%2Fx%2Fim%2Fm1%2F1&kgs=99ac7810a65b7a21&shem=abme%2Ctrie

Additive tech takes on short-run press brake tooling. (n.d.). https://images.app.goo.gl/eDwX3qDoPVJPWwg47

Sheet-Metal Mini Workshop Press Brake – STL, STEP. (n.d.). https://images.app.goo.gl/b48pfCp2WovckFub6

Hydraulic bending press machine for sheet metal. (n.d.). https://images.app.goo.gl/2HFN5TStq81xFWWP9

Appendix B.8 List of requirements v2

Value characteristics	Values	Creteria (wishes and requirements)- Analysis Phase	Creteria/status V1	Creteria/status V2
Desirability	dv-1 Facilitates experiential learning.	1. The workshop around the setup facilitates a form of external reflection.		
		2. Students need to be actively involved in using the setup. This means they have to use their senses and interact with it to get results.		
	dv-2 Adaptable to courses with a productive failure approach	3. The setup can serve as a standalone educational tool or as part of a productive failure workshop.		
	dv-3 User-friendly design	4. >80% should be able to use the setup without a manual.		
		5. The time to setup the setup should be smaller than using the setup.		
		6. The setup should be accessible from all sides.		
	dv- 4 Exciting design	- insights		
	dv-5 Accessible design	6. The setup should be accessible from all sides.		
		7. The setup should be able to be used by other faculties and therefore online displayed.		
		8. The setup should be visible in the current daily workday of a student.		
		9. Missing parts have to be discovered before using the setup.		
	dv-6 Intruiging design	- insights		29. The setup should be actuated other than manually.
	dv-7 Enhancing confidence			
	dv-8 Educational setup Appeal		24. The setup should have a robust and sturdy feel.	
			26. Use premium materials	
Feasibility	fv-1 Making real products/parts		21. The prototype makes real products/parts	
	fv-2 Safe design	13. CE-certified (safety standard)		
	fv-3 Working prototype (TRL 7-Prototype demonstration in operational environment)		TRL-4	TRL-6
	fv-4 Production ready		- insight	
	fv-5 Cost estimate is known		70	110
	fv-6 User tested	user test v0		user test v2
	fv-7 Integration in IDE education	15. 350 Students can experience the setup in one afternoon (4 hours).		
		14. To make the setup applicable for several courses it should educate on different bloom levels.		
		12. Keep cost low (later on define price minimum)		
	fv-8 Portability and storage	20. Make it easy to store, and relocate		
Viability	vv -1 Low investment costs	12. Keep cost low (later on define price minimum)	12. Keep cost for one configuration €150	
	vv- 2 Low maintenance	9. Missing parts have to be discovered before using the setup.		
		10. Low parts cost (later define the price)		
	vv-3 High return of investment	11. The setup should be versatile and educate students with different engineering principles		
		18. The setup is multi-functional		
	vv-4 Versatile and Scalability	14. To make the setup applicable for several courses it should educate on different bloom levels.	14. The setup should educate on different bloom levels.	
			28. The setup should be modular	
	vv-5 Enhances education results	~~16. The setup should educate on the subject product structure.~~	Out of scope	
		17. The setup should educate on the Manufacturing methods and materials	17. The setup should educate on the Manufacturing methods and materials and its oppertunities and limitations.	
			23. The vacuum former configuration should use a manual heating gun.	
			25. The setup should have the same (but smaller) limitations as professional machines to discover design requirements.	
			22. The vacuum former configuration should allow different molds to be used.	
			27. The setup should be assembled by the student	
		~~18. The setup should educate on the subject NVM lines, forces and deflection.~~	Out of scope	
	vv-6 Different focus than market alternatives		12. Keep cost low (later on define price minimum)	

Appendix C.1 - BOM

Batch						60	stukprijs	60	stukprijs	10	stukprijs	10	stukprijs
Basic													
Top + bottom plate	1,00	st	247 Tailor steel	-		900	**18**	1515,5	30,31	282	28,2	423,8	42,38
12v voeding	1,00	st	Aliexpress	-		200	**4**	200	4	40	4	40	4
Up down switch	1,00	st	Amazon.nl		1,33		**1,33**		1,33		1,33		1,33
C14 Inbat Module Plug Zekering Schakelaar	1,00	st	Amazon.nl		2		**2**		2		2		2
PVC pijp 90 degrees	1,00	st	Hornbach		2,25		**2,25**		2,25		2,25		2,25
PVC pijp 32mm	0,16	m	Hornbach		1,8		**0,288**		0,288		0,288		0,288
Dopmoer m10	2,00	st	Hornbach		0,34		**0,68**						
Blindklink moer m4	8,00	st	Amazon.nl		0,085		**0,68**						
trespa frezen	0,03	m^2	Florian Van Reije		100		**3,64**		3,64		3,64		3,64
trespa plaatje	0,03	m^2	HPL op maat		55		1,848		1,848		1,848		1,848
Draad 1.5^m2	1,00	m	Electramat		0,1		**0,1**		**0,1**		**0,1**		**0,1**
M4 boutjes	8	st	Hornbach		0,09		**0,72**		**0,72**		**5,76**		**5,76**
Kabelschoentjes	14,00	st	Amazon.nl		0,025		**0,35**		**0,35**		**4,9**		**4,9**
Subtotaal							35,886		46,836		54,316		68,496
Press							**0**		0		0		0
Lineare actuator 1000N stroke 150mm	1,00	st	Aliexpress		**25,59**		**25,59**		25,59		25,59		25,59
M10 Moeren	8,00	st	Hornbach		0,1		**0,8**		**0,8**		**0,8**		**0,8**
Stale kokers 40x40x2	1,00	st	247 Tailor steel			443	**8,86**	670,85	**13,417**	215	**21,5**	277,62	**27,762**
DC Power Jack Socket 5,5 x 2,1 mm DC	1,00	st	Amazon.nl		1,8		**1,8**		**1,8**		**1,8**		**1,8**
Subtotaal							37,05		41,607		49,69		55,952
Metaal kanten													
staale slider , onder en boven	1,00	st	247 Tailorsteel			354	**7,08**	573	11,46	186	18,6	248	24,8
20mm Buisje op bovengeleider 20mm	0,02	m	PMB/metaalshopper.nl			1,97	**0,0394**	2,36	0,0472	1,97	0,197	2,36	0,236
140mm Buisje staanders 2x	0,28	m	PMB/metaalshopper.nl			27,58	**0,5516**	33,04	0,6608	27,58	2,758	33,04	3,304
3D print mal boven en onder			PMB				**1**		1		1		1
M10 moeren	2,00	st	Hornbach				**0,2**		**0,2**		**0,2**		**0,2**
M10 Draadeind 200 2x	0,40	m	Hornbach				**0,72**		**0,72**		**0,72**		**0,72**
Subtotaal							9,591		14,088		23,475		30,26
Vacuum vormen													
xxxx	1,00	st											
trespa frezen	0,15	m^2	Florian Van Reije				**18,89**		**18,89**		**18,89**		**18,89**
trespa plaatje	0,15	m^2	HPL op maat				10,098		10,098		10,098		10,098
Subtotaal							29,988		29,988		29,988		29,988
Spuitgieten													
xxxx	1,00	st											
trespa frezen	0,03	m^2	Florian Van Reije				**3,64**		**3,64**		**3,64**		**3,64**
trespa plaatje	0,03	m^2	HPL op maat				1,848		1,848		1,848		1,848
Subtotaal							5,488		5,488		5,488		5,488
Verpakking													
xxxx													
trespa frezen													
trespa plaatje													
Subtotaal													
Overige kosten													
Assemblage Loon	3,00	uur	Zelf		40		**120**		**120**		**120**		**120**
Poedercoaten	1,00	Batch	?		250	300	**6**		**0**	250	**25**		**0**
Subtotaal						0	126	0	120	0	145	0	120

Appendix C.2 -What type of press 2.0

How to make pneumatic a valid option?

Initial analysis Pneumatic

Pneumatic piston

+

Switch gear, pressure regulator

+

Compressor + Tank

+ Cheap piston
+ Lot of force
+ Easy to operate
+ Can stop half way
-Expensive compressor
-Many components
-Big components
-Can not stop half way.
-compressor makes a lot of sound

(Nevon Projects, 2022)

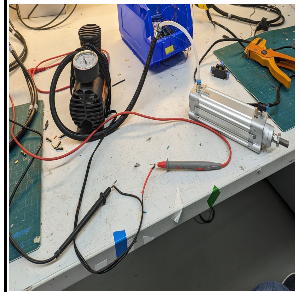
Central pneumatics of PMB

Specs
Pressure max: 8 bar
Volume: unlimited

Price
Compressor: external
Switch hear/tubes: 20
Cylinder: 40-250
Total; 60 euro

-Can not be used in studio or central hall
+cheap
+constant force

12V Pump



Specs
Pressure max: 10 bar
Volume: none
Sound± Loud
Speed=**35L/min**
Required time for 1000N
Long!

Price
Compressor: 25
Switch hear/tubes: 20
Cylinder: 40-250
Total; 85 euro

-Builds up pressure very slowly, not realistic to real machines.
+cheap
+constant force

Mini compressor tankless

Specs
Pressure max: 8bar
Volume: none
Sound+ 95 dB

Price
Compressor: 95
Switch hear/tubes: 20
Cylinder: 40-250
Total; 150 euro

-very loud.
+cheap
+constant force

Mini compressor with tank

Specs
Pressure max: 8bar
Volume: none
Sound 59 dB

Price
Compressor: 120
Switch hear/tubes: 20
Cylinder: 40-250
Total; 180 euro

-expensive
-big

Mini compressor tankless

Specs
Pressure max: 2.5/3bar
Volume: 5L
Required bore diameter for 1000N
65mm diameter

Price
Compressor: 95
Switch hear/tubes: 20
Cylinder: 40-250
Total; 150 euro

-low pressure, bike pump could do more but less volume.
+cheap
+constant force

Appendix D.1 - Experience questions

Voelde je je betrokken bij de leermethode?

Helemaal niet betrokken — ○ ○ ○ ○ ○ — Heel erg betrokken

Was het interigerend/boeiend om te leren?

Helemaal niet interigerend — ○ ○ ○ ○ ○ — Heel erg interigerend

Werd je enthousiast van de leermethode?

Totaal niet — ○ ○ ○ ○ ○ — Ik werd laaiend enthausiast

Hoe gebruiksvriendelijk was de leermethode?

Totaal niet gebruiksvriendelijk — ○ ○ ○ ○ ○ — Super gebruiksvriendelijk

Hoe zelf verzekerd ben je om thermovormen toe te passen?

Totaal niet zelfverzekerd — ○ ○ ○ ○ ○ — Super zelfverzekerd

Heb je zelf nog iets toe te voegen?

Appendix D.2.1 - Questionaire

Afstudeeronderzoek educatieve productie machines

Super bedankt voor je deelname aan mijn onderzoek van afgelopen week. Het is nu tijd voor het mini tentamen, en daarna kun je die voucher in ontvangst nemen.

Vul de vragen naar eigen kennis in; antwoorden (online) opzoeken zal de onderzoeksresultaten negatief beïnvloeden.

Als je het leuk vindt om mijn afstudeerpresentatie bij te wonen, dan ben je van harte uitgenodigd op 21 augustus om 13:30 uur op IO. Voor de exacte locatie kun je mij een berichtje sturen.

* Verplichte vraag

1. Welke leermethode heb je gevolgd? *

Markeer slechts één ovaal.

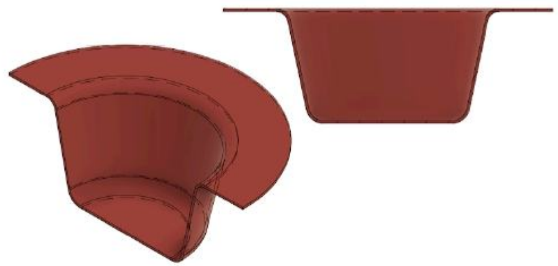
- Ik leerde uit een boek en een filmpje
- Ik heb de vacuümvorm machine gebruikt met daarna een filmpje

2. Welke opleiding volg je en in welk studie jaar zit je? *

Geef aan in welke mate de dwarsdoorsnedes van deze thermogevormde producten exact kunnen worden geproduceerd

4. Waarom? *

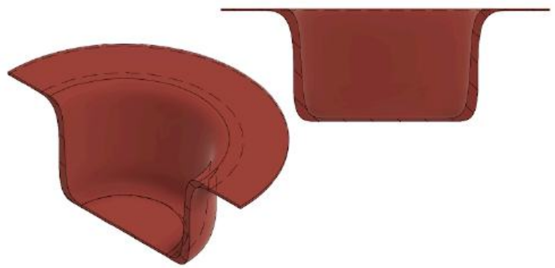
3. *



Markeer slechts één ovaal.

- Makkelijk
- Erg moeilijk
- Onmogelijk
- Weet ik niet

5. *



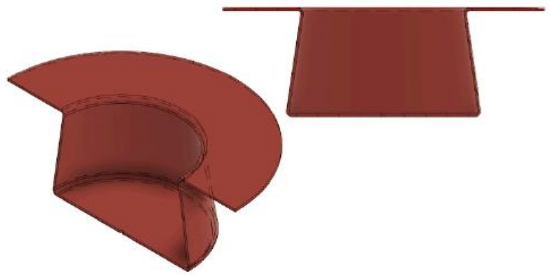
Markeer slechts één ovaal.

- Makkelijk
- Erg moeilijk
- Onmogelijk
- Weet ik niet

Appendix D.2.2 - Questionaire

6. Waarom? *

7. *



Markeer slechts één ovaal.

- Makkelijk
- Erg moeilijk
- Onmogelijk
- Weet ik niet

8. Waarom? *

9. Kruis aan welke producten gemaakt kunnen worden doormiddel van thermovormen *

Vink alle toepasselijke opties aan.

	Thermovormen	Ander productie proces
Bonbon verpakking	☐	☐
Hamburger verpakking	☐	☐
RVS (metaal) bakje	☐	☐
PET-fles	☐	☐

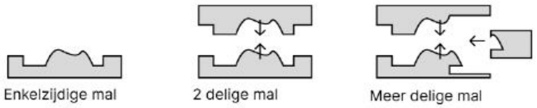
Appendix D.2.2 - Questionaire

10. Kruis hieronder aan welke uitspraken juist zijn. *

Vink alle toepasselijke opties aan.

- ☐ Bij vacuümvormen wordt een thermoplastisch materiaal opgewarmd totdat het vloeibaar is, waarna het tegen de mal wordt gezogen.
- ☐ Typische materialen die prima geschikt zijn voor vacuümvormen zijn ABS, PMMA en PE, maar ook zachte metalen zoals aluminium.
- ☐ Met vacuümvormen kan een lage vormcomplexiteit behaald worden.
- ☐ Vacuümvormen heeft lage mal/gereedschapskosten, maar kan arbeidsintensief zijn.
- ☐ Bij de productie van vacuümgevormde producten zijn er geen afvalmaterialen.

11. Wat voor soort mal wordt er het meest gebruikt bij thermovormen? *



Markeer slechts één ovaal.

- ◯ Enkelzijdige mal
- ◯ 2 Delige mal
- ◯ Meer delige mal
- ◯ Weet ik niet

- ◯ Anders: ____________

13. Voel je zelfverzekerd genoeg om een product te ontwerpen dat kan worden geproduceerd met de productietechniek vacuümvormen? *

Markeer slechts één ovaal.

	1	2	3	4	5	
Tota	◯	◯	◯	◯	◯	Super zelfverzekerd

Super bedankt voor het invullen! Voor het ontvangen van de €20 Albertheijn voucher zou ik graag de volgende gegevens willen noteren. (De voucher wordt alleen verzonden als de questionnaire serieus is ingevuld.)
Mocht je de voucher niet in ontvangst willen nemen/je adres prive willen houden kun je deze vragen leeg laten.

14. Voor naam en achternaam

____

15. Postcode, huisnummer (en toevoeging)

____

12. Je hebt ontdekt dat er een gat in de markt is voor windschermkappen van vintage brommers. Je ontwerpt een windscherm kap zoals te zien op de afbeelding. Je wilt er 100.000 gaan produceren. Welk productie proces kies je? *

Markeer slechts één ovaal.

- ◯ Plastic spuitgieten
- ◯ Plastic extruderen
- ◯ Thermovormen
- ◯ Week ik niet

16. Straatnaam

____

17. Plaats

____

18. Zouden we je over ongeveer een half jaar opnieuw kunnen contacteren voor een vergelijkbaar mini-tentamen? Dit kan ons helpen om te onderzoeken hoe lang de informatie blijft hangen en zal ons nog meer inzicht geven. Alvast bedankt! *

Markeer slechts één ovaal.

- ◯ Ja
- ◯ Nee
- ◯ Anders: ____________

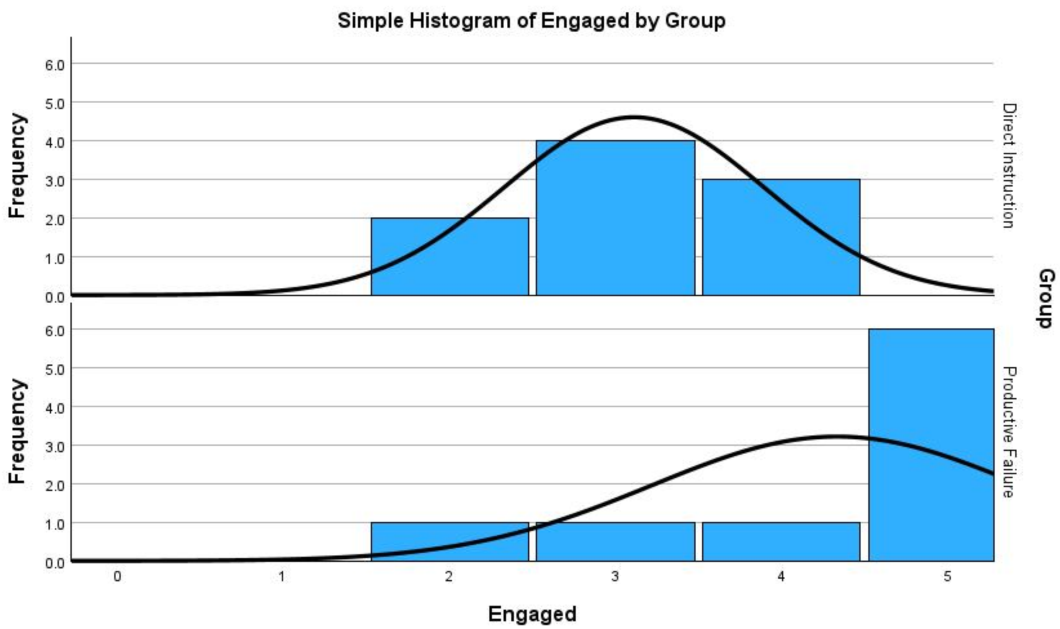
Appendix D.3 - Experience Results

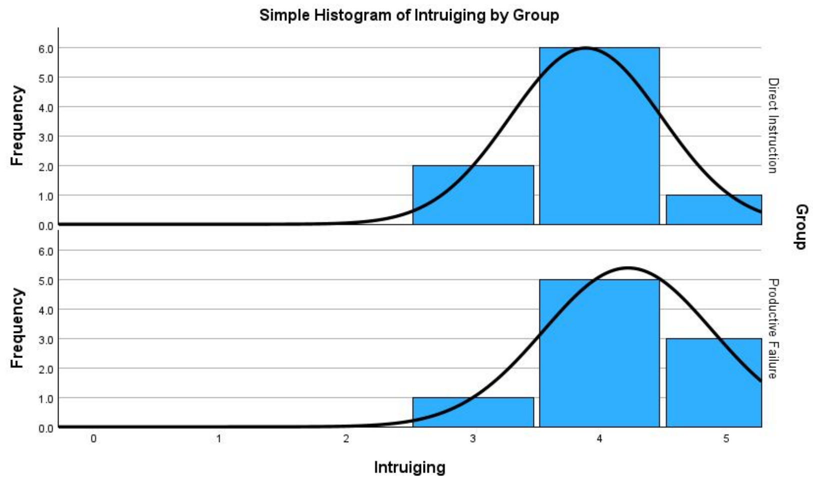
Independent Samples Test

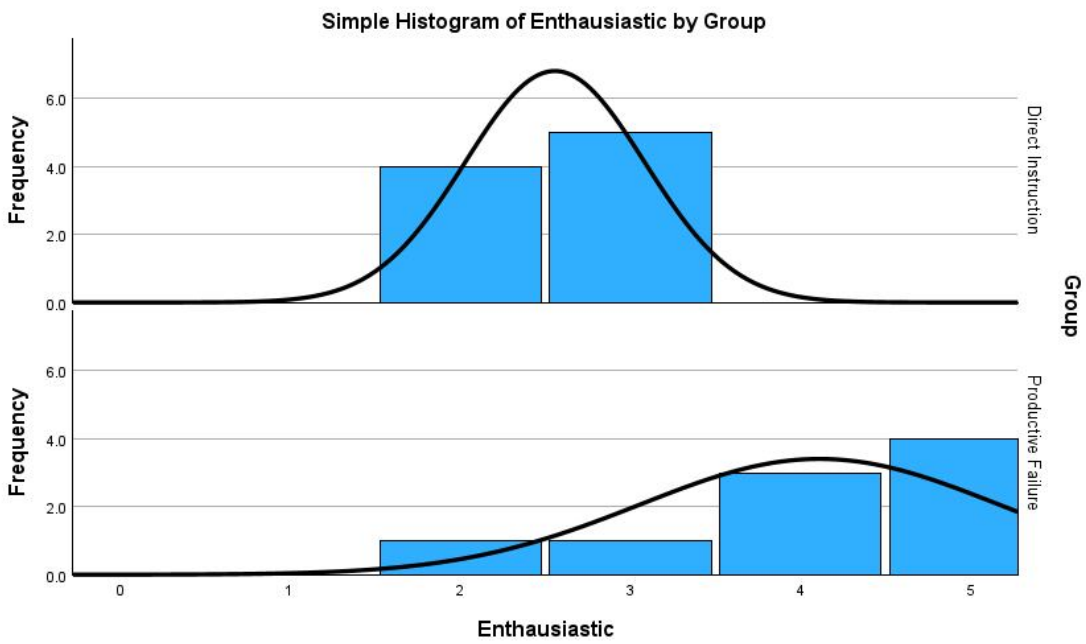
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Engaged	Equal variances assumed	1.369	.259	-2.688	16	.016	-1.22222	.45474	-2.18623	-.25821
	Equal variances not assumed			-2.688	14.313	.017	-1.22222	.45474	-2.19555	-.24890
Intruiged	Equal variances assumed	.419	.527	-1.114	16	.282	-.33333	.29918	-.96756	.30089
	Equal variances not assumed			-1.114	15.831	.282	-.33333	.29918	-.96811	.30144
Enthausiastic	Equal variances assumed	1.917	.185	-3.960	16	.001	-1.55556	.39284	-2.38833	-.72278
	Equal variances not assumed			-3.960	11.765	.002	-1.55556	.39284	-2.41338	-.69773
Userfriendly	Equal variances assumed	.219	.646	2.309	16	.035	.66667	.28868	.05470	1.27863
	Equal variances not assumed			2.309	14.400	.036	.66667	.28868	.04913	1.28420
Confident	Equal variances assumed	2.353	.147	-2.292	14	.038	-1.20635	.52631	-2.33518	-.07752
	Equal variances not assumed			-2.520	11.146	.028	-1.20635	.47863	-2.25813	-.15457

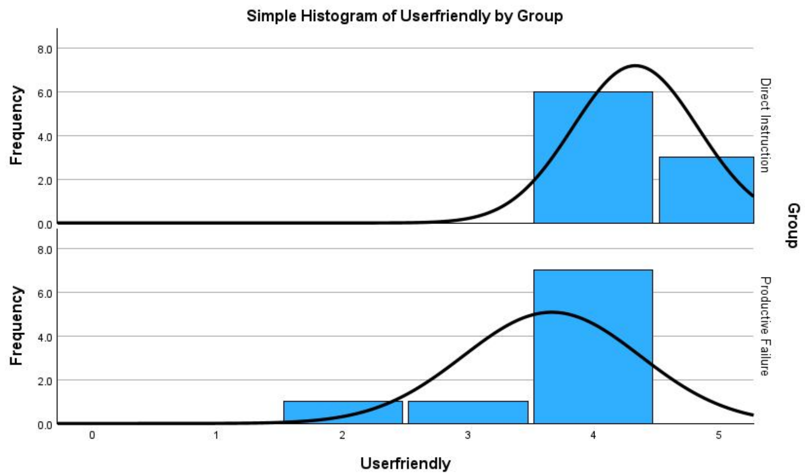
The results of students' perception/experience show that there is a significant difference in all experience questions (orange and green squares). We also see that the mean difference is greater on the questions about enthusiasm, confidence, and engagement. Intriguing and user-friendliness show less mean difference. By analyzing the 95% confidence interval of the mean difference, we see that the mean difference is indeed significant for all except how intrigued the students felt (gray squares). In all cases, the experiential setup scores higher in terms of positive perception of the learning process than direct instruction.

Appendix D.3 - Experience Results









Appendix D.3 - Experience Results

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Amount_correct_per_group	PF	7	5.1429	2.79455	1.05624
	Di	7	5.2857	2.05866	.77810

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
Amount_correct_per_group	Equal variances assumed	.389	.544	-.109	12	.458	.915	-.14286	1.31190	-3.00125	2.71553
	Equal variances not assumed			-.109	11.031	.458	.915	-.14286	1.31190	-3.02936	2.74364

Independent Samples Effect Sizes

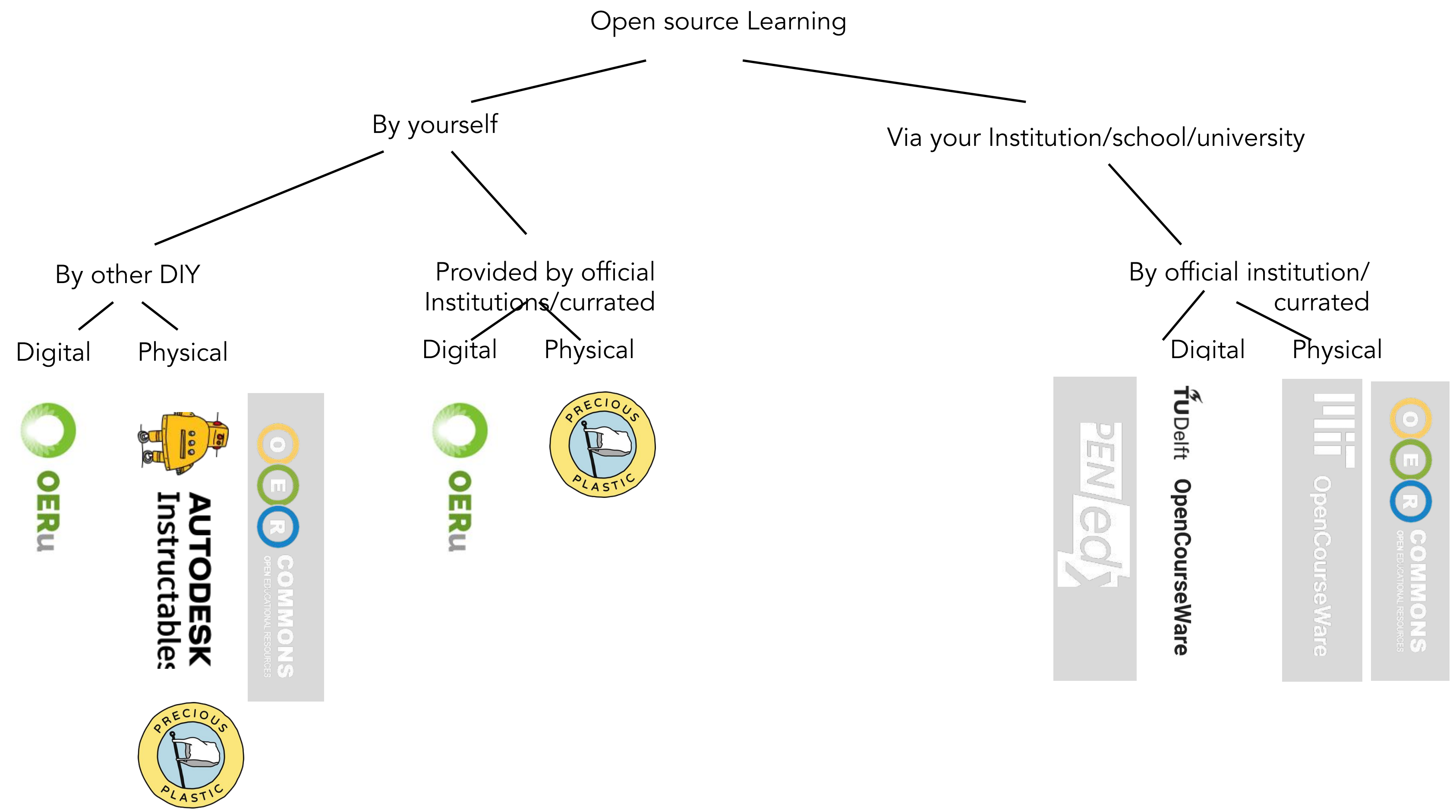
		Standardizer[a]	Point Estimate	95% Confidence Interval	
				Lower	Upper
Amount_correct_per_group	Cohen's d	2.45435	-.058	-1.105	.991
	Hedges' correction	2.62233	-.054	-1.034	.927
	Glass's delta	2.05866	-.069	-1.115	.982

a. The denominator used in estimating the effect sizes.
Cohen's d uses the pooled standard deviation.
Hedges' correction uses the pooled standard deviation, plus a correction factor.
Glass's delta uses the sample standard deviation of the control (i.e., the second) group.

Appendix D.4 List of criteria V3

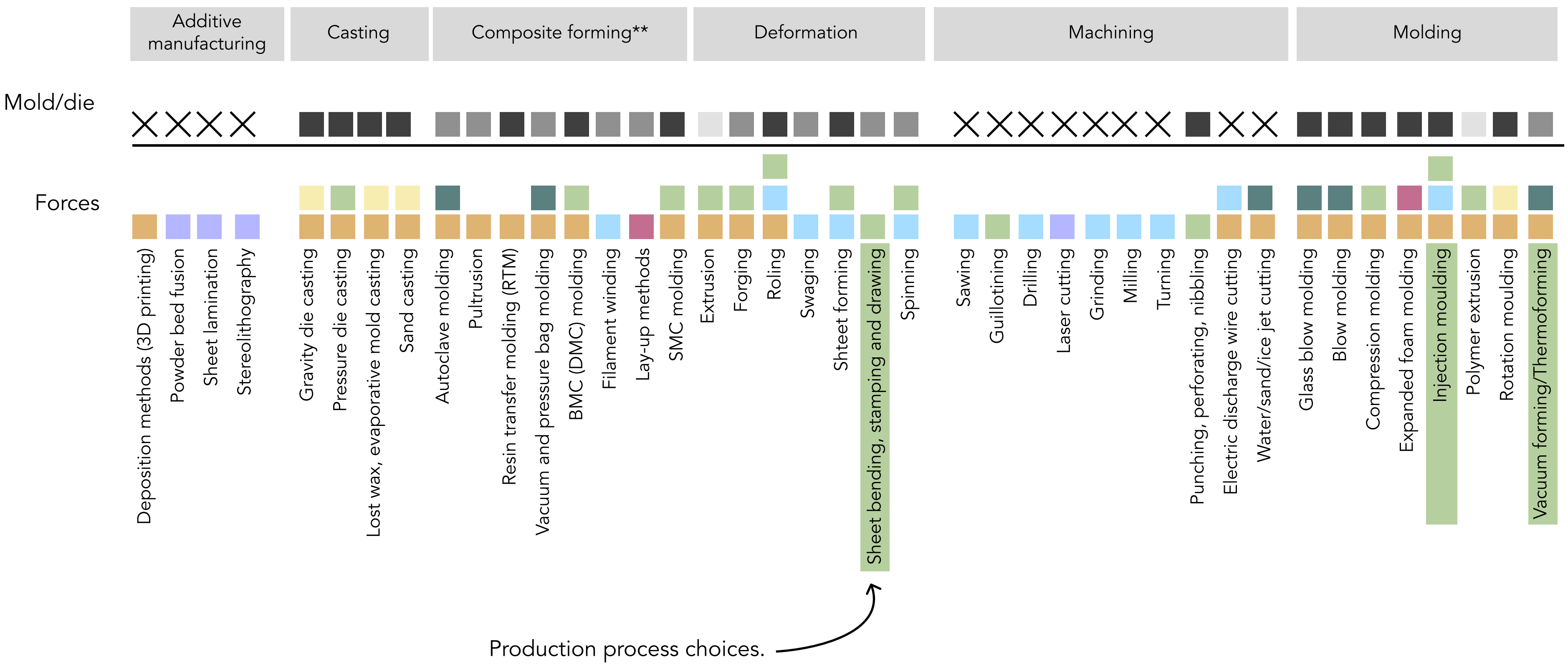
	Values	Creteria (wishes and requirements)- Analysis Phase	Creteria/status V1	z	Creteria/status V3
Desirability	dv-1 Facilitates experiential learning.	1. The workshop around the setup facilitates a form of external reflection.			
		2. Students need to be actively involved in using the setup. This means they have to use their senses and interact with it to get results.			
	dv-2 Adaptable to courses with a productive failure approach	3. The setup can serve as a standalone educational tool or as part of a productive failure workshop.			
	dv-3 User-friendly design	4. >80% should be able to use the setup without a manual.			
		5. The time to setup the setup should be smaller than using the setup.			
		6. The setup should be accessible from all sides.			
			30. Connecting the vacuum hose from the bottom does not work, It has to be from the side or top.		
				31 Use sub-assemblies to keep the focus of student on Learning objectives.	
				35. Replace bolt connections for snap-fits or mechanical fit	
				38. Error-proof the design, it can only be assembled in the right way.	
				39. The configurations need to be easy distinguishable.	
					New Requirement - 40. The setup should facilitate solutions for students with limited prior know
	dv- 4 Exciting design	- insights			
	dv-5 Accessible design	6. The setup should be accessible from all sides.			
		7. The setup should be able to be used by other faculties and therefore online displayed.			
		8. The setup should be visible in the current daily workday of a student.			
		9. Missing parts have to be discovered before using the setup.			
	dv-6 Intruiging design	- insights		29. The setup should be actuated other than manually.	
	dv-7 Enhancing education experience				-insight
	dv-8 Educational setup Appeal		24. The setup should have a robust and sturdy feel.		
			26. Use premium materials		
Feasibility	fv-1 Making real products/parts		21. The prototype makes real products/parts		
			32. Use a PTC element as heating for education on lowest Bloom level.		
				33. The injection molding configuration should have a place holder for molds.	
	fv-2 Safe design	13. CE-certified (safety standard)			
	fv-3 Working prototype (TRL 7-Prototype demonstration in operational environment)		TRL-4	TRL-6	TRL-7
	fv-4 Production ready		- insight		
	fv-5 Cost estimate is known		70	110	100
	fv-6 User tested	user test v0		user test v2	user test v3
				37. Injection molding is user test ready	
	fv-7Integration in IDE education	15. 350 Students can experience the setup in one afternoon (4 hours).			
		14. To make the setup applicable for several courses it should educate on different bloom levels.			
		12. Keep cost low (later on define price minimum)			
	fv-8 Portability and storage	20. Make it easy to store, and relocate			
Viabilty	vv -1 Low investment costs	12. Keep cost low (later on define price minimum)	12. Keep cost for one configuration <All €150		
				34. Remove redundant parts	
	vv- 2 Low maintenance	9. Missing parts have to be discovered before using the setup.			
		10. Low parts cost (later define the price)			
				36. Connect things to the linear actuator trough the conventional hole.	
	vv-3 High return of investment	11. The setup should be versatile and educate students with different engineering principles			
		18. The setup is multi-functional			
	vv-4 Versatile and Scalability	14. To make the setup applicable for several courses it should educate on different bloom levels.	14. The setup should educate on different bloom levels.		
			28. The setup should be modular		
	vv-5 Enhances education results	~~16. The setup should educate on the subject product structure.~~	Out of scope		
		17. The setup should educate on the Manufacturing methods and materials	17. The setup should educate on the Manufacturing methods and materials and its oppertunities and limitations.		
			23. The vacuum former configuration should use a manual heating gun.		
			25. The setup should have the same (but smaller) limitations as professional machines to discover design requirements.		
			22. The vacuum former configuration should allow different molds to be used.		
			27. The setup should be assembled by the student		
		~~18. The setup should educate on the subject NVM lines, forces and deflection.~~	Out of scope		
	vv-6 Different focus than market alternatives		12. Keep cost low (later on define price minimum)		
	vv-7 Sustainability				

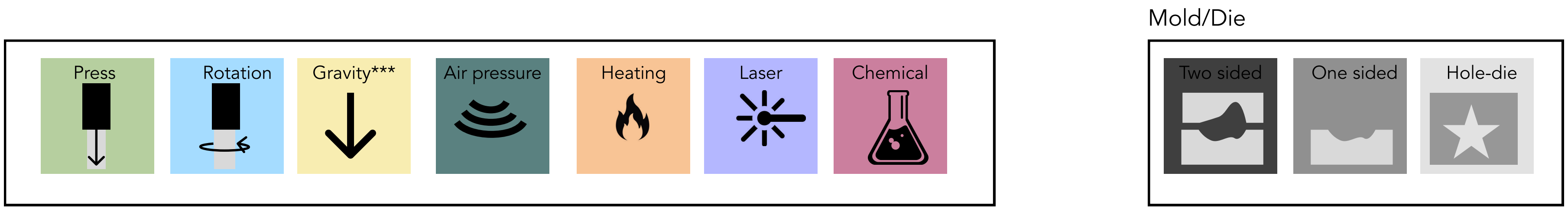
Appendix E.1 - Open Educational Resources



Appendix E.2 - Manufacturing methods*

This infographic shows almost all manufacturing processes and their forces + die. This is used to choose the productions processes in prototype v1. Many machines have overlap in forces that are use or dies.





*'Joining and surface treatments' such as adhesives, welding, fasteners, painting or anodizing are out of scope.
** Very rarely used processes are left out of scope.
*** On earth gravity is always used. This force is only used when its the core force of the proces.