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Rapid prototyping tools

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MASTER THESIS SPRING 2016
FOR
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Rapid prototyping tools.

The democratizing of rapid-prototyping tools is claimed to induce an industrial production revolution. Not only have tools as 3D-printers and laser cutters become cheaper and cheaper but the accessibility has increased through the opening of public or semi-public makerspaces around the world. This means that the original user profile of such machinery, being production and mechanical engineers, has changed into more novel users approaching the tools for the first time and thereby having very limited experience and knowledge on the capabilities of such machines. This provides the risk that they fail to utilize the possibilities of the tools and never go beyond the level of making aesthetic laser cutted signs or jewellery of small 3D printed figures. Moreover we believe that the lack of knowledge leads to a whole-product-focus when it comes to prototyping tools. Instead we believe the value should be to master the decision power of which tool to use for which sub-component of a prototype - a so-called sub-part-focus.

By addressing the change of primary user of rapid prototyping tools as well as communicating the sub-part-focus rather than the whole-product-focus this master thesis is divided in two parts.

Firstly it maps barriers of engagement of the 3 most used tools in the state-of-the-art prototyping space; the laser cutter, the mill and the 3D printer. Further it holds the tools up against the functionalities presented in the TRIZ framework and suggest which tool fit the different functionalities the best.

Activities in this master will encompass as minimum:

- Building the same carefully chosen object on all three tools and describe challenges
- Map out your own personal barriers of engagement of the different tools (since both of us are considered novel users)
- Interview users of the newly established Protomore in Molde
- Interview workshop responsible of Skylab DTU about their experiences with novel users in their lab.
- Map relevant TRIZ functionalities or principles and match them with certain tools.
- Prepare the material for academic publication (data, synthesis and analysis, graphs, etc.)

Learning Goals:
- A deep understanding of barriers of novel users to approach the tools
- A deep understanding the core benefits of a laser cutter, 3D printer and a mill
- Explore how the TRIZ framework could be used in a prototyping workshop
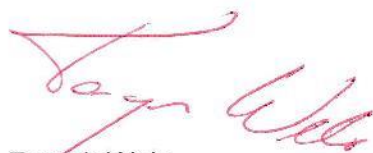
Formal requirements:

Three weeks after start of the thesis work, an A3 sheet illustrating the work is to be handed in. A template for this presentation is available on the IPM's web site under the menu "Masteroppgave" (https://www.ntnu.edu/web/ipm/master-thesis). This sheet should be updated one week before the master's thesis is submitted.

Risk assessment of experimental activities shall always be performed. Experimental work defined in the problem description shall be planed and risk assessed up-front and within 3 weeks after receiving the problem text. Any specific experimental activities which are not properly covered by the general risk assessment shall be particularly assessed before performing the experimental work. Risk assessments should be signed by the supervisor and copies shall be included in the appendix of the thesis.

The thesis should include the signed problem text, and be written as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents, etc. During preparation of the text, the candidate should make efforts to create a well arranged and well written report. To ease the evaluation of the thesis, it is important to cross-reference text, tables and figures. For evaluation of the work a thorough discussion of results is appreciated.

The thesis shall be submitted electronically via DAIM, NTNU's system for Digital Archiving and Submission of Master's theses.

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Abstract

This paper is the description of the method and result of the master project of Petter Ildgruben at the Department of Engineering Design and Materials (IPM) at the Norwegian University of Science and Technology (NTNU) in the spring of 2016. The goal of this master's thesis has been to explore the barriers that novel users face in makerspaces, specifically when interacting with the 3D printer, the laser cutter and the Computer Numerical Control (CNC) mill and how to overcome them.

The first chapter presents the background for the thesis. Some of the literature and earlier experiments related to this topic is explored and some lacking knowledge is identified which forms the groundwork for the thesis. Chapter two presents the methods of research employed to explore these barriers, which consists of experiencing the barriers myself, interviewing other novel users and observing users interacting with the machines. The results give grounds for a new method of teaching users how to use makerspaces, what is new about this method is the focus on barriers and making the novel user aware of the ones that he overcomes to build confidence. A tool to ease the decision of what machine to use is also proposed, this tool utilizes the TRIZ principles to help machine selection based on product characteristics. This tool is meant as a template for further development in each makerspace considering what machines are available.

Key Words: Prototyping, Makerspace, 3D-printer, laser cutter, mill, early-stage prototyping, novel users, action research, teaching in makerspaces

Sammendrag

Denne oppgaven viser metoden i og resultated av Petter Ildgrubens masterprosjekt ved Institutt for produktutvikling og materialer (IPM) ved Norges teknisk-naturvitenskapelige universitet (NTNU) våren 2016. Denne masteroppgavens mål har vært å utforske barrierene nye brukere møter i makerspace og hvordan man kan overvinne dem. Spesifikt, de barrierene de nye brukerne møter ved bruk av 3D printer, laserkutter og Computer numerical control (CNC) fres og hvordan.

Det første kapittelet presenterer oppgavens bakgrunn. I dette kapittelet blir noe av litteraturen relatert til dette temaet gjennomgått, og manglende kunnskap blir identifisert. Denne manglende kunnskapen danner grunnlaget for oppgaven. Kapittel to presenterer forskningsmetodene som er brukt for å utforske barrierene. Metodene består av erfare disse barrierene selv gjennom å være en ny bruker av disse maskinene, intervjue andre nye brukere og å observere hvordan folk bruker maskinene. Resultatene gir grunnlag for en ny måte å lære brukere i makerspace hvordan man skal bruke maskinene på. Det som er nytt med denne metoden er fokuset på barrierer og hvordan disse oppdages for hver bruker. Deres overvinning av disse barrierene hjelper brukeren til å bygge selvsikkerhet. Et verktøy for å hjelpe den nye brukeren til å bestemme hvilken maskin som skal brukes i produksjonen av deres prototype foreslås også, dette verktøyet bruker TRIZ's prinsipper til å gjøre maskinvalg enklere ved å vurdere prototypens karakteristikker. Dette verktøyet er ment som et grunnlag man kan bygge videre på etterhvert som man ser hvilke maskiner man har tilgjengelig i et spesifikt makerspace.

Nøkkelord: Prototyping, makerspace, 3D-printer, laserkutter, fres, tidlig stadium prototyping, nye brukere, handlingsforskning, læring i makerspace

Acknowledgements

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Introduction

During product development it is a big advantage to be able to present something physical to stakeholders when presenting the product. This gives the stakeholders a sense of quality and progression as they can actually touch a version of the product. It also eases communication and explanation of ideas for design changes and additional functions. (Houde and Hill, 1997)

The prototypes used in early stage of product development are typically quite low fidelity to avoid big costs, but with the introduction of the 3D-printer, the laser cutter and the mill into the early product development-stage these types of prototypes can have higher fidelity without a big increase in effort or cost. The reasons this would be desirable are many, they could range from wanting to show stakeholders a higher quality to secure investments or wanting to show peers an idea in a more complete format to explain thought processes. A good product development process requires communication, and as Houde and Hill emphasizes, a prototypes core function is to communicate information. This puts the prototype at the core of product development.

The methods of production for these types of prototypes are not very advanced, but might seem so to the unexperienced eye. The barriers that one might experience when first interacting with these machines may seem insurmountable, but they might not be as tall as they seem at first. In this paper different barriers will be identified and explored.

The goal of this master's thesis has been to explore the 3D printer, the laser cutter and the CNC mill and discover the barriers that novel users face when interacting with these. After this the goal was to explore how the TRIZ system could be applied to learning in makerspaces and develop a method of teaching novel users to use these machines. This master's thesis has been done with help from Ph.D. Candidate Matilde Bisballe Jensen and with the supervision of Prof. Martin Steinert at IPM, NTNU. A risk assessment has been conducted and is attached as Attachment B.

This paper is structured to guide the reader through the essence of the literature considered relevant to this research, present the method of the research, a small refreshing of what the different production methods are, then present the findings and from them draw a conclusion. The first chapter "Background" will show research done on this or similar topics, and literature related to the process of learning in makerspaces. After this, the "Tools" chapter will present the 3D printer, laser cutter and the mill. The third chapter "Methodology" will present

the methods of research that has been employed and how they have been used in this thesis, as well as the reason for the choice of these three machines. The fourth chapter "Findings" will present the processed findings from the research methods, with a conclusion of what they mean at the end of this chapter. After this the "Discussion" chapter will discuss the findings and present what can be drawn from the findings. Following this is a chapter on the "Limitations of the study", which will explore flaws in the research methods employed. At the end there is a "Conclusion", which will summarize what has been done and present the contribution to the literature on the subject. Following this is a literature list and attachments at the very end.

Background

In this chapter we seek to investigate what is being said about makerspaces and how to teach novel users how to use them. We also explore research done related to these topics.

What is a Makerspace?

Diana Rendina (2015) offers a definition of a makerspace in her article, *Defining Makerspaces: What the Research Says*: "A Makerspace is a place where students can gather to create, invent, tinker, explore and discover using a variety of tools and materials.". Roslund and Rodgers (2014) offer a slightly different definition in their book: *Makerspaces*: "Makerspaces is a general term for a place where people get together to make things. Makerspaces might focus on electronics, robotics, woodworking, sewing, laser cutting, programming, or some combination of these skills.".

There are many definitions of a makerspace available, but the essence remains the same, a makerspace is an arena in which you are given the tools to make what your creativity wants. These tools can differ a great deal, they can be directed towards electronics and software, a "Hackerspace", they can be more towards physical/mechanical products, or softer fabrics. The contents of a makerspace depend on what it is geared towards, but can generally be any machine or tool used for making something. Some examples of these tools/machines include a sewing machine and tools, a 3D-printer, a CNC mill, a laser cutter, a soldering station, breadboards, wires and Arduino, but only the imagination stops what tools can be put into a makerspace. One important thing to not forget is that makerspaces is not all about the tools. The social aspect of a makerspace is not to be underestimated, it is a community. Bouncing ideas with other users and getting to take part in their pool of knowledge concerning the use of machines as well as their personal experiences in regards to your specific project can be an even greater help than the machines themselves sometimes.

How to learn in a makerspace

There is some research on how to teach the skills needed in a makerspace, but it seems to be incomplete, it seems to be lacking a definitive answer. Luz Rivas (2014) made an attempt at an experimental set up she describes in "Creating a Classroom Makerspace". In this example, Rivas creates a makerspace for 5th grade girls to spark their interest in the art of making. She considers it a success because the kids have started to learn by doing and enjoy sharing what

they have made. In this paper we can see a classic example of the thought that Learning by doing is the best approach for learning practical skills, complemented by coaching. Another approach is proposed by Loertscher (2015) in his paper on "*The Virtual Makerspace*". Loertscher suggested that while the makerspace is under development, virtual tools should be used. These virtual makerspaces are described as informal virtual environments where students and adults can create, build and invent. Loertscher says that it would be a 24/7 virtual space that should not be part of an assignment, it should be something that you are not tested in and a place where you are in command of your own learning. The idea from Loertscher is that this will prepare you for using the physical makerspace when it is finished. In their *Makerspace Playbook*, Hlubinka, Dougherty, Thomas, Chang, Hefer, Alexander and Mcguire (2013) emphasize the importance of play and the celebrating of other Makers. They say that the origin of the Maker movement comes from enthusiasts who play with technology to learn it and maintain that this mindset is important. In his book, *Play: How it Shapes the Brain, Opens the Imagination and Invigorates the Soul,* Dr. Brown (2009) tells a story about how the Jet Propulsion Laboratory (JPL) noticed a difference in the engineers they hired, where the ones that tinkered and played with projects in their youth were more suited for the tasks they wanted to solve. When Hlubinka, Dougherty, Thomas, Chang, Hefer, Alexander and Mcguire mention celebrating other Makers, they talk about how the community in a makerspace is what is important and how one should use each other for learning, not just standardized tools, but encourage each other to build motivation and mastery.

Hlubinka, Dougherty, Thomas, Chang, Hefer, Alexander and Mcguire (2013) also say that users of all ages need to be trained in proper and safe use of the tools before using them. They present a checklist before you should use the machines: Attend Lecture, Watch Video, Do worksheet, Safety Test (100%), Demo it and Use the tool on your own. This view on the importance of safety is supported in the manuals for each tool, in the Ultimaker 2 manual there is a "caution" or "warning" mark below almost all steps for the first part of the manual. And in the manual for the mill there is even a warning about the fact that the machine contains chemicals known to cause cancer, birth defects and other reproductive harm. This is because there is lead in the machine, in fact, the first 12 pages of the English part are dedicated to the "To ensure safe use"-part with warnings about electrocution, the danger of fire, burns, pinches and such things. This is a major part of the literature.

An interesting question that Hielscher and Smith (2014) bring up in their paper on reviewing the research literature related to community-based digital fabrication workshops is whether

the availability of these makerspaces and the ease of manufacturing "reskill" or "deskill". By reskill they mean that the passive consumers now can be engaged in the creative process of making a product. This can be done in their spare time, and does not require years of practicing the craft to master it. Deskill is thought to be the fact that the processes that earlier required finesse and skill are now being automated so that anyone can do it without having much skill related to the crafting of objects. As they present it, this can be seen as a debate between two parties, the hobbyist (the novel user) and the skilled factory worker (the experienced user). In this debate the interests of the novel user are to have easier access and more automation, more user friendly machines and interfaces, where the experienced user would want to protect his own interests. His interests are mainly to keep his job and to be able to practice his skills without "dumbing down" the machines (as he might see this strive for user friendliness). This notion of reskilling is what we seek to explore. Many things have happened to lower the barriers that keep the novel user from interacting with the machines in a makerspace, but what is enough? Where does the line go that a novel user dares interact and use the equipment? Is it at that point not interesting for an experienced user to use these same machines?

What is the difference between a novel and an experienced in a maker space? What skills are required for prototyping with the 3D printer, the laser cutter and the mill? Thomas Parker (2013) suggest that *making* requires two skillsets and the confidence to try something new. The first skillset he says is simply tool skills, not only knowing how to use a tool safely, but also when to use it and if there are other tools better suited for the task. These skills are easily taught and learned, a simple demonstration and common sense is often enough to reach a sufficient level of understanding of the tools. The second set of skills he suggests is problem-solving skills and a diagnostic skillset. These skills include understanding why your solution will not work, coming up with creative solutions to the problems and managing one's own emotions during the process. If you get flustered or annoyed it is easy to start ignoring small, but important things, so keeping a cool is important. These are skills that can be taught, but not as easily according to Thomas Parker. They are more efficiently learned through experience and coaching.

As for the last point, confidence can be a harder to teach, and takes time. Luz Rivas said that after the success of her making a makerspace for girls, after they had gotten time to succeed in the makerspace, they had become independent and they would now pursue projects that once

seemed impossible to them. It seems a good way to learn confidence is to be given the room to succeed.

Barriers to engagement

Barrier:

«something (such as a fence or natural obstacle) that prevents or blocks movement from one place to another»

«a law, rule, problem, etc., that makes something difficult or impossible»

- simple definition by merriam webster

A barrier is defined as something that prevents you from performing a specific action. It can be something physical that is stopping you, it can be rules, norms or mindsets that prevent you from doing something. In this context, a barrier of engagement is meant as a perceived problem by the novel user that prevents their interaction with the prototyping tools or the makerspace in general.

The author of the book "MayDay! Asking for Help in Times of Need", Nora Klaver, was interviewed by The New York Times along with the author of "Help! The Original Human Dilemma", Garret Keizer and manager of education services at Advantage Credit Counseling Services, Caryn Bilotta (Tugend, 2007). They had a lot of insight into social barriers. Reasons why asking for help is hard. One fear they say, is that when asking for help you will be surrendering all control and the person assisting will take over the entire project, another is the fear of what someone might ask in return, "What is it going to cost me?". A third fear is that the power balance will shift in a relationship towards the helper and that this may spiral so that you feel in debt towards a friend who won't accept your help in return. When these are what comes to mind when a person has the need for help in a makerspace it can be hard to ask, and therefore to learn.

In her book *Understanding Librarians*, Hull (2011) remarks that human beings have an in-built fear of the unknown. This makes us cautious of unfamiliar situations, she compares this with the feeling of dread that a person can feel before he enters a room of unknown people and mentions that the ease with which this feeling can be surmounted depends on the person, their personality and previous experience with similar situations. Another example she mentions is where students transition from using a public library to using an academic one, in

this example the unknown is emphasized by the students lack of skill and knowledge of what is available in the library. This might serve as a barrier that keeps the student from using the academic library to its potential. Hull also mentions the barrier she calls "Losing face", as she so eloquently puts it: "Nobody likes to look stupid!". Argyle (1994) remarks that some groups are more exposed to this barrier than others, among them are young people who are forming their self-image and people who have just had a major change in their life such as change of nationality, job or social class.

TRIZ

"Theory of the resolution of invention-related tasks" or "Theory of inventive problem solving"

The TRIZ framework proposes a method of problem solving that can be applied to most design related problems. TRIZ provides a systemic and scientific approach to understand and solve the problems and challenges you might have in your design or production process. One of the pillars of TRIZ is the thought that problems often stem from a need to choose the

Figure 1: TRIZ Method

lesser of two evils, this means that a trade-off or a compromise between two contradicting needs is often necessary. This is what TRIZ seeks to combat, by using the TRIZ system you are encouraged to find creative solutions to difficult problems that result in inventive and good solutions that does not necessarily require a trade-off. The main tool that one use is the 40 principles of TRIZ which is a result of the study of many successful patents and their solution of problems in their design. These principles have been generalized so that they are easier to understand and apply to a specific problem. (Barry, domb and Slocum, 2014)
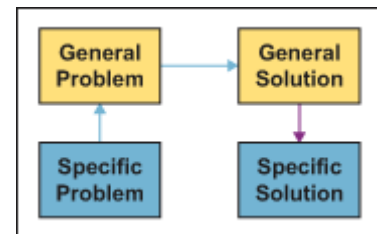
Machines

3D – printer

3D printing is a method of additive manufacturing, which means that material is being added to build an object. In 3D-printing usually layers of a material are put on top of each other and fastened by some mechanic, a bonding agent or the melting of the material itself. There are lots of different forms of 3D-printing, using different materials as the main difference.

Usual materials for printing are plastics, for example PLA and ABS in smaller 3D printers, one such printer is shown in Figure 2. This printer melts the material and deposes it in succeeding layers from the bottom and up. Some other printers use paper, where one sheet is put on top of another and then cut and glued, at the end of this process you have to manually remove the excess paper. This results in a very fine resolution (the thickness of a sheet of paper), but takes quite a while for larger prototypes. Another method of 3D printing is done with a powder printer. This method spreads a powder (the additive material) over the cross section of the product, then a print head moves over and deposes a liquid binding material in the pattern of that layer of the print. After this another thin layer of powder is yet again spread across the cross section and the process is repeated until the product is done. The printers are CNC-machines which use a software to find the patterns of each layer automatically.
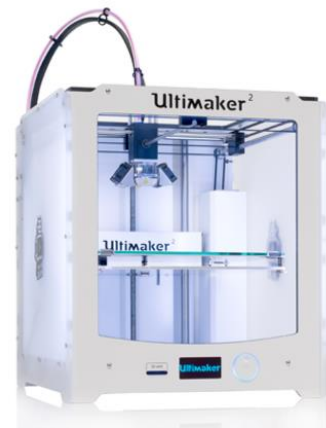
Figure 2: Ultimaker 2 3D printer

The printer used for making the 3D printed prototypes in this thesis work is the Ultimaker 2 (Figure 2).

Laser cutter

Laser cutting is a production method that utilizes a laser to cut materials. This is used for many purposes from industrial grade manufacturing of parts to small size prototypes. The lasers used in a laser cutter can be identified as three main types, CO_2 laser, neodymium(Nd) laser and neodymium yttrium-aluminium-garnet (Nd YAG) (Todd, Allen, Alting 1994, p186). These different types of lasers have different applications, presented in Table 1.

Table 1: Types of lasers and their use

Description	Application
CO_2	Cutting Boring Engraving Drilling
Nd	High energy pulses Low repetition speed Boring
Nd YAG	Very high energy pulses Boring/drilling Engraving

The materials that can be cut vary from stainless steel and aluminium to plywood and cardboard (GravoGraph LS1000XP, 2016), the trick to cutting the different materials lie in configuring the laser correctly. Ways to configure the laser includes a power setting where

you regulate the effect of the laser, a speed setting where you control how fast the laser will trace the pattern and a count of how many times the laser will trace the pattern.

A laser cutter can also be used for engraving. The power of the laser is turned down and used to leave a mark on the surface of the material rather than to cut straight through. This function can be used to give products a finishing touch that heightens the esthetical outlook of the product.

Figure 3: GravoGraph LS1000XP laser cutter

The laser cutter used for production of the prototypes mentioned in this thesis work is the GravoGraph LS1000XP laser cutter (Figure 3).

Mill

The milling process is a large category of operations. It is characterized as the machining process with rotary cutters which removes material. The variety of products that can be made in a mill is vast, from small scale weak foam prototypes to large scale strong steel products (Brown and Sharpe, 1914). After CNC came to milling it has become an even more precise tool than it was before, the CNC eliminates the human error part of the production and can produce the same part with fine tolerances over and over again. A modern mill

Figure 4: Roland MDX-540 milling machine

usually houses different machining tools, which it can switch between as the software sees fit. Classically a mill has been a top-down machining tool, which means that the workpiece can have work done only from one side at a time, can be worked from different angles by changing the fastening. This is no longer the only case, there are mills with multiple axis that enables them to work on a piece of material from many angles without having to change the fastening. These mills are complex to operate manually as there are multiple joints to control

and many mistakes to make, therefore these mills are always CNC. The axis of movement for these mills range from four and up.

A classical top-down mill will have three axes which is defined by the x-, y- and z-coordinate, which means horizontal movement in two axes plus one vertical. These mills are either CNC or manual, although almost all modern mills will have a CNC function, they can also be operated manually by controlling the machine via a software.

Figure 5: Principles of milling

The machining is done by feeding the workpiece or moving the tool. In Figure 5, the concept is shown, in this case the workpiece is being fed in the direction of the arrow. For the Roland MDX-540 the tool is the part being moved, one can imagine the tool moving in the opposite direction (of what is shown in Figure 5) while the material remains stationary.

The mill that was for production of the prototypes in this thesis work is the Roland MDX-540 (Figure 4).

Methodology

Action research

Action research is a research paradigm which helps you to gain knowledge through action. "Action research goes beyond the notion that theory can inform practice, to a recognition that theory can and should be generated through practice." (Brydon-Miller, Greenwood, Maguire, 2003, pp. 15). In this article action research is described as a method of gaining knowledge through action, which can be compared to walking through uncharted territory and drawing a map, rather than looking at a map and planning a trip.

Mills (2014) suggests some main components for action research in *Action Research: A Guide for the Teacher Researcher*. The components he suggests can be summarized as follows:

- Define what the purpose of the study is:
  The purpose of this study is to gain increased knowledge of how to teach the skills necessary to succeeding in a makerspace.

- Describe what you want to learn and who will be a part of the research:
  We wanted to learn what skills were necessary in a makerspace and how these skills can be taught to novel users. We also wanted to learn what barriers a novel users perceive that make interaction with the tools in a makerspace harder and ways to lower these barriers.
  The research would be undertaken as a master's thesis by Petter Ildgruben and Ph.D. candidate Matilde Bisballe Jensen, additionally there would be other makerspace users and novel users from establishing makerspaces contributing to the research.

- Describe negotiations that need to be undertaken and develop a timeline and statement of resources
  Necessary negotiations would be to get permission to use the help provided in the makerspace as part of the study.
  The timeline is very clear as it is a master's thesis scheduled for one semester, this means that it was five months from start to finish, this getting the action part started priority, before using the last part for writing a paper.
  Statement of resources includes all the machines available in the makerspace "TrollLabs" at NTNU Verkstedsteknisk. This is a GravoGraph LS 1000 XP laser

cutter, an Ultimaker 2 3D printer and a MDX-540 Roland milling machine along with material available at any time for each of these machines.

- Develop data collection ideas

Data collection methods would include: Observation, using the machines and the makerspace as a whole as a novel user and learn them (be the actor) and verify or falsify by qualitative interview of other novel users.

- Set the plan into action

These principles have been applied in this research, but one concern remains. In action research one observes a person or a system. Generalizing from this subject to a broader sense may be hard to do properly, because even if a statement is true for a select system it may not be true for another system. This is often viewed as the major weakness of action research. There are however several ways that can be used to alleviate this weakness. Through for example having other studies in different settings yield the same result, having the same action produce the same results in different settings or using relevant or indirectly-relevant literature test the relevance of the findings some generalizability can be claimed. (Dick and Swepson, 2013). This lead to the usage of the triangulation method.

Triangulation method

Triangulation is defined as the use of multiple methods or perspectives for the collection and interpretation of data about a phenomenon, in order to obtain an accurate representation of the reality (Pollit and Hungler, 1999). The reasoning behind using a triangulation method is that alone the results of qualitative research may seem unreliable, but when backed up by each other, they gain credibility. Foss and Ellefsen (2002) write in their paper on *The value of combining qualitative and quantitative approaches in nursing research by means of method triangulation from* that with a combination of methods it is possible to move between different kinds of knowledge. For example, between broad general knowledge and a deeper insight. Between macro and micro levels, like the society or community in a makerspace and personal perception. The methods of triangulation have been chosen to be the active "Be the actor" research, supported by observation and qualitative interviews of other novel users. In

addition to these active methods, the research will be supported by a study of relevant literature both of online less formal and of academic resources

Be The Actor

"Action learning is based on the idea that we learn better by doing. The "doing" in action learning consists of real problems" (Raelin, Lebien, 1993, pp. 1). When combining action learning with being the actor, you will in this case take the role of the actor (the novel user) and learn through doing and experiencing the same things as novel users do and experience. You will learn using the machines and experience barriers of engagement in the same way that other novel users will.

Observation

"What people say they believe and say that they do are often contradicted by their behavior" (Mach, Woodsong, MacQueen, Guest and Namey 2005, pp. 13). In this book it is said that this is a very human behavior which can make the results of methods like interviewing and focus groups less certain. Not only due to the participants perceived reality or embellishment thereof, but also due to forgetfulness. Observation is a method that aims to learn things from the way that people normally act, and to do that the observed should ideally be ignorant of the fact that he is being observed.

Qualitative research by Interviews

"The (in-depth) interview is a technique designed to elicit a vivid picture of the participant's perspective on the research topic" (Mach, Woodsong, MacQueen, Guest and Namey 2005, pp. 29). The reason why this is a good supplement to this method is the fact that interviews is a useful tool for learning about the perspectives of individuals, since it often is a one-on-one conversation. The role of the interviewer is to get information that the participant has (Malterud 2008). In this case, the information was about the subjects perceived barriers for engagement with the machines in a makerspace and general attitude towards makerspaces.

The interviews will serve as a mode of qualitative research as well as a way to verify that the barriers experienced in the "Be the Actor" part are relevant for other novel users as well. It will help to generalize the action research.

Seven people was interviewed, six of them were from the crew starting a makerspace at the department of computer and information science at NTNU, one was a novel with an interest

in the machines available. All of them were novel users with different expectations and hopes for the makerspace.

An interview guide is attached in attachment A.

Online Research

The online research that has been conducted include looking into what other people has done in order to learn using rapid prototyping tools such as these machines and looking into online guides and resources for learning and motivation.

One blog that was read detailed a person's journey from being a complete novel user with nothing but an interest. His goal was to buy a 3D printer and see if he could, in 200 days, "master the 3D-printing technology and use it for something useful in the daily life". This is no scientific research paper, but it offers insight into how other people went about learning the machines. Another source that was looked into was www.instructibles.com, which has guides for many things, among them are guides and tips & tricks for getting to know and easing in to 3D printing with some easy prints.

Literature Research

The searching process for literature on or related to the subject of learning in makerspaces has been done on Google Scholar and on NTNUs online resource Oria which lets you search the library's collected resources. In regards to source criticism some sources, like Qualitative Research Methods: A Data Collector's Field Guide, seems quite reliable. These are published books which is straight to the point with few or no opinions from the writers, just objective presentation of the information and research. Then there are articles such as Luz Rivas' "*Creating a Classroom Makerspace*" which has been published in an award winning magazine (Educational Horizons). This also seems reliable due to the nature of the magazine, this type of literature is more opinionated, but is very honest about where the opinions shine through. A third type of resource are research papers, these papers have varied in their credibility and it mostly depends on the description of their methods, which if lacking may make the paper seem unreliable. Lastly there has been some webpages that has been used (such as www.makezine.com), the webpages have been read with critical eyes and checked for references. The pages referred to here have been mostly opinions and suggestions, but they have been helpful as they put words to thoughts that is hard to explain. For this specific reference (www.makezine.com) the author was Thomas Parker whose bio says that he was the project director for the DARPA-funded MENTOR makerspace program and that he has built

airplanes capable of 200mph among other things, if this is true it is a man of experience who has got a good grip on the things he talks about. He is also listed as an important person in keeping multiple sites running, so it is hard to imagine such a profiled character lying about his credentials. A quick google search will confirm from multiple sources that this man is who the website says he is, and this I think, makes this web article reliable.

Why these three machines?

The focus of this paper has been to investigate barriers for novel users with 3D printers, laser cutters and CNC mills, there could have been many machines chosen as the focus of the research like soldering stations, a lathe, a sewing machine, microcontrollers/mechatronics and so on. However, as shown by Jensen, Semb, Vindal and Steinert (2016) in their paper on *State of the Art of Makerspaces – Success Criteria when Designing Makerspaces for Norwegian Industrial Companies* the 3D printer, laser cutter and the CNC mill are the three most chosen manufacturing machines to put in a (Norwegian) makerspace. It follows that these three machines are the ones that novel users are the most likely to have to deal with when entering a makerspace, which is why the thesis should be pointed in this direction.

Setting the action plan into action

The Being the actor method of data collection would consist of two major parts. The first part would be to make three prototypes in all three machines to emphasize the strengths and weaknesses of each machine and figure out ways to use this to ease the learning process. The second part would be to continue making objects in the machines to test functions and characteristics other than the ones explored in the first part. This was also meant to explore the machines further in order to gain a deeper understanding of their applications and to find good ways of teaching the use of these machines.

Action learning with prototypes

The objects that would be made in three different machines were chosen to showcase different characteristics of the machines. The three characteristics that would be the machines ability to create a hollow object (a bottle), a thin light object (a glider) and their ability to make a strong, durable part (a gear). After seeing the machines in action it was decided to make another product that would showcase the good surface finish you can obtain with a mill (an injection mold).

Three objects in three machines

The 3D model of the bottle was made in CAD. The same 3D model was used for all machines. This was done at the beginning of the semester when a lot of people were in the physical prototyping part of their projects, this meant that many people with experience were available in the makerspace. This

Figure 6: Three bottles from three machines

was used for asking for help with all machines. The 3D printer was the first one to get tested. The flask was imported into Cura, the Ultimaker software, and transferred to an SD card. After that the printing was started, it was a good first print. For the laser cutter, 123D make was used to make the 3D model of the bottle into a 3D puzzle made from interlocking parts, then cut and then assembled. The bottle was cut in cardboard. As for the mill, the bottle was machined in wood. It was two-stage milling process as the bottle had to be flipped over half way into the process for the other side to be machined.

The gears were created using www.woodgears.ca which is an online tool that enables you to easily construct two gears that fit together. These gears were used for the laser cutter directly and as a template for construction of a 3D model for the mill and the 3D printer. The print took several hours, the laser cutting took half a minute and the milling took about 20 minutes. A lot of help was received with the crafting of the bottle, but with the gears it was decided to try without receiving much help, since the basics was already gone through with the bottle craft. This had some mixed results with the mill, the mill requires a calibration of the tools in its magazine before each machining process, this is done by the mill automatically, but requires a distance sensor to be plugged in correctly. It was forgotten to plug this in which resulted in a broken sensor since the tool did not stop in time. Also, the fastening of the workpiece was improperly done. The gears came loose during the machining and was not fully completed (see the left side of the top left gear in Figure 7).

Figure 7: Gears from three machines

The glider was downloaded from www.thingiverse.com and was printed without any problems. 123Dmake was used to slice up the 3D model. The design of the glider was very thin which made the only real option to cut a single cross-section and use it as a glider as-is. The design had to be slightly altered for this, there was a tail rudder that would have to fit into a hole at the back of the body, this hole had to be altered to be the thickness of the material as the thickness of a laser cut object will always be the thickness of the material. As for the mill this was a hard nut to crack, the hole for the tail rudder was too narrow for the tools available. Even if the hole is widened, the inner radius of an edge will never be smaller than the radius of the tools. The

Figure 8: The only successful glider (from 3D printer)

tools were too coarse for a fine enough radius to be made that the tail rudder could fit in to. Additionally, the thin design made the whole object fragile, which made the wings break off from the vibration from the cutting.

After this it was decided to try for another product in the three machines that would showcase the fine surface finish obtainable in the mill. Another student was at this time working on his molds and we teamed up for making his molds in the 3D printer, the mill and the laser cutter.
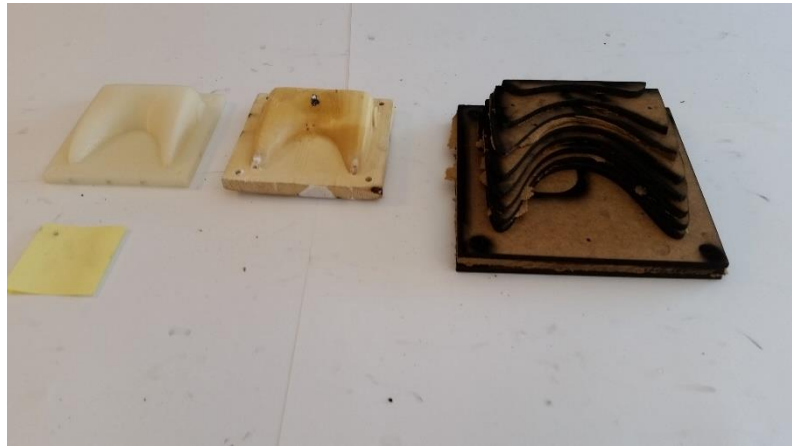
Figure 9: Three (half) molds from three machines

Testing different functions on the machines

The objects made in the different machines provided a good gateway into the use of the machines. After getting used to them and learning the basics it was time to test some different functions. These could be types of products presented on web pages, features of observed products, tips from the software or doing precision work.

Laser cutter

Living hinge

The first type of product we had heard about and wanted to test was the living hinge design, this is a hinge design that allows for a rigid material to become flexible in parts of the product. After searching www.thingiverse.com for designs with living hinge as a natural part of their design a cup holder design was downloaded. In this design the handle was made from a single piece of material (in this case plywood) with the two bends having the living hinge design, which would be flexible enough to bend 90 degrees without wear or tear. This was a very straight forward cut as there were no problems with the download. The mistake made here was not clear until after the cut was done. The material used was too thick for the initial design. The holes that the handle stiffener was meant to fit through in the handle was designed for a 4mm thick plywood plate, the plate that was used was 6mm thick. so the parts could not be assembled, but the living hinge was a success (Figure 10), which was the reason behind this cut. It was decided to make another product to test living hinge even more. The living hinge pattern was from the last design was copied, and multiplied. A pencil holder was designed with four wall pieces that had the bend made with the living hinge pattern. The parts were cut nicely and fit together (Figure 11 and 12).

Figure 10: Living hinge pattern

Figure 11: Living hinge pencil holder parts
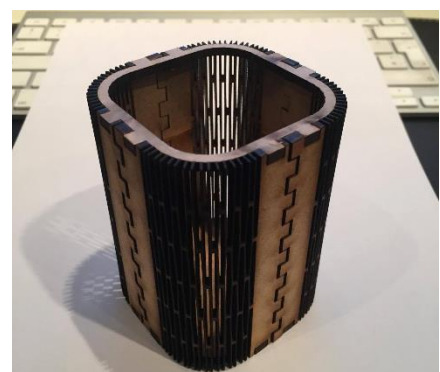
Figure 12: Living hinge pencil holder assembled

All of the parts cut as of this point has been a coarse cut, except for the living hinge cut. That posed a question, how fine cuts are possible? The thought for testing this went to some sort of pattern that was complex with many twists and turns, exactly that was found on

Figure 13: Fine cut burned vs unburned

www.thingiverse.com after some searching. The pattern was downloaded and the cut was started. It was a tea light holder with four walls with patterns on them, the patterns were of a tree with many branches and an animal per side. The first time this cut was done it had to be aborted because the material had caught fire. This was due to a combination of too high effect, too slow movement and the fact that the laser would spend extra time in each area because there were so many thin branches to trace (Figure 13). To combat this, another cut with lower power, faster movement and two repetitions was started. The result was good, the parts were assembled (Figure 14) and glued together.

Figure 14: Fine cut tealight holder assembled

3D printer

Overhang

The Cura software offers a function to change 'View Mode' that lets you get a visual on some factors you might want to consider. One of these is "Overhang", which shows you parts of the print that is unsupported by previous layers, which means that the printing of these parts would start mid-air, examples of this can be arms stretched out from the body, the underbody of a car (carried by the wheels) or the part of the roof that stretches beyond the wall of a house. Printing these objects would require some sort of support structure due to their overhang and the fact that this printer is unable to start printing mid-air. It was decided to print a knight standing at the ready with a sword and a shield. These were two items that would probably need some sort of support as they start mid-air if seen from the bottom up. First, a print without support structure was started to see how needed it would be. It was left alone for quite a while, when it started printing in mid-air and was just wasting material, the print

Figure 15: Aborted knight print, no shield

Figure 16: Knight, with support structure under the sword and shield, between the legs and under the arms

was aborted. (Figure 15). The print was restarted with the option "touching buildplate" activated, this also gave too little support since only a small part of the knight's shield was outside the plate he was standing on. This setting will only print support structure if it does not touch the rest of the print. The print was aborted and restarted yet again with the proper settings activated, "everywhere". This means that the printer will print support structure everywhere it sees the need for it. The print was restarted and came out with a support structure that carried both the sword and the shield nicely (Figure 16). weight. Printing with "Lines" support structure means that the printer will put parallel lines up to the point the print

starts and use them as a foundation for continuing the print. The alternative support structure is "Grid", which prints a grid instead of lines, this is a stronger and harder to remove structure. The blade of the sword did not need get support structure as the cut-off point was in this print set to not give extra supports to parts which had an overhang angle of less than 60. The overhang angle is defined by how far a layer is from the preceding layer (Figure 17)
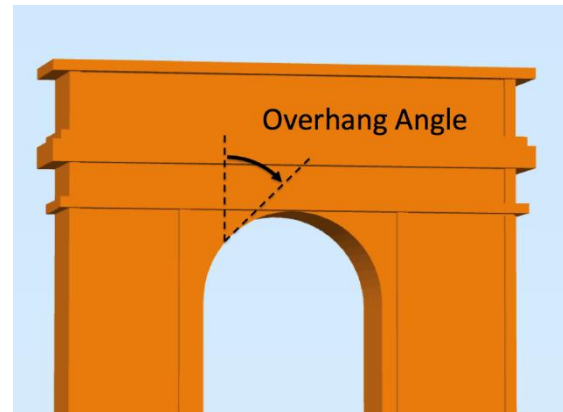
Figure 17: Overhang angle

Different fill percentage

The tooltip over this option says that you can obtain a good stable print with the standard 20% fill, which means that 20% of the filled space within the CAD model will be filled with material in the physical print. This is often enough for a model to be printed successfully. Some keychain Martians was printed (Figure 18) with different fill percentage to get a feel for the impact of this option. With too low a fill there was not enough material for the upper layers to build upon and the print did not complete properly (Figure 19). For a higher fill percentage, the print looked identical to the first, but took longer to print, however, this is a more robust product.

Figure 18: Keychain Martian, 20% fill

Figure 19: Keychain Martian, 5% fill

Mill

Manual milling

The mill offers the option to mill manually. This is something that is often done on an analog mill, but also usually possible with a CNC mill. The already milled top part of the mold would be the template, and the goal was to make a part as close to that as possible, with manual controls. The manual controls of the panel are hard to control for machining the movement is binary on/off. This makes using the manual function very step-wise, as you often want to take a step back and see where you are. and it is hard to get a smooth surface. With an analog mill you can often control the movement in different axis by turning a wheel, and you can turn them at any speed you want, this feels more in touch with the machining process as you can feel the resistance from the material in a completely different way. The end result was not good, and to emphasize that the part was thrown away by someone else, probably thinking it was a practice workpiece that had outlived its usefulness. There were a lot of curved surfaces on this particular job, which makes it harder to do manually with a binary control set, but with a lot of straight surfaces it might be easier, and the manual function can be used to greater effect.

Observation

For this paper, observation has been used as one of the pillars of the triangulation method. The main usage of this method has been to map the work flow of each machine. By observing users from the Computer Aided Design (CAD) stage to a complete physical prototype we can learn what issues people have and how they overcome them. The observation has been with subject was unaware that they were being observed. The observation concerned the subject's direct interaction with the machines and their methods of acquiring aid when needed. Oral consent was given after the observation to use the findings for this paper.

The observation was executed for two subjects per machine. The observation would continue for as long as the subject was active at the machine, if the subject left the machine after a long print, cut or machining process had been started, the observation would end.

Using interviews as a means of evaluating

The interviews were scheduled with novel users who expressed their interest after being offered a quick tutorial to using the laser cutter. The main goal of the interviews was to get the participants to express their barriers and their reservation towards a makerspace without influence from the interviewer. This was done by crafting the interview to be objective and direct in its posing of questions. The interview consisted of seven questions and three action points for the participants. The first question was about general expectations towards a makerspace and the rest were follow-up questions to their picks and answers to the action points. The action points asked them to write their barriers towards each of the machines on a map that depicted their journey from a novel user to each

Figure 20: The interview had the participants map their barriers onto a "map" of the makerspace

of the three machines (Figure 20). The post its would symbolize the barriers they faced on their paths. In the second and third action points the participants were asked to pick out five emotions they related to a makerspace and five emotions they did not relate to a makerspace from a pool of 40 preprinted cards with different emotions written on them.

Analysis and Findings

Through the different methods it became clear that there were several factors or skills that would make overcoming barriers in a makerspace easier. These will be presented here.

The importance of friendly helpers

Through the observations a significant difference between the two observed subjects who used the 3D printer was noted. The big difference was that the first subject gave up on his print after failing to get it started properly three times, it seemed the print head was clogged in some way. Some hours later a different subject was struggling with the same problem. His reaction was not to give up, but to ask if anyone knew how he could get it going. The helper who troubleshooted with him found a solution and got the clog out of the machine. After that the print started very easily and seemed to work fine. This showcases three effects that friendly helpers can have. Firstly, the second subject did not give up because a helper was available. Secondly, the subject might have learned how this problem can be solved and will have an easier time the next time he encounters it. Lastly, the second subject got to finish his print and got to experience the mastery of finishing an object that proved troublesome, he overcame a barrier. This is also what was experienced in the "Be the actor" research, the help that you can get from friendly helpers at the time of need is often more impactful than having to sit down and search tens of forums of similar, but not quite the same problems until you find one that helps you a little bit. By being helped one can overcome obstacles quickly and move on to building experience and confidence instead of being stuck and getting flustered.

Software and digital skills

When interacting with these machines it almost always happens through a software, without the proper knowledge of or the drive to learn the different softwares and digital aids available it can be a daunting task to learn how to use these machines. This was experienced through the action research both with being the actor and observation. When being the actor in a makerspace some of these softwares are unavoidable (3D printer, laser cutter and milling software), some are very useful to have experience with (CAD software) and some provide a nice complement to these other ones (Online resources, 123D Make). The last category is one that the community in a makerspace and friendly helpers will be able to assist with suggestions to. To make something with a 3D printer or a mill, you need a 3D model of the object you are going to make, and for the laser cutter you will need the outline drawn for the laser to trace. This means that you need a modelling software.

Solidworks/NX

These are standard 3D CAD-programs which allow you to make 3D models and 2D machine drawings of your ideas. Both the programs rely on the entry of constraints that define the boundaries of the object. These constraints can be either numerical or geometrical. The process of building a 3D model often starts out with making a drawing in 2D which is then extruded. If the part has symmetry, the process can be simplified by designing only a part of the final design and then mirroring the part. An example of this can be a gear where you can model only a part with one tooth and then mirror the part the desired number of times.

Using these types of software require some training and can look hard. For NX there is a good web resource www.nxportalen.com, which contains many tutorials and ways to get going with small courses. For SolidWorks there is a lot of help integrated in the program which guide you through the process of modelling, these can be very helpful if you are a new and unexperienced user. These guides function as interactive courses where you are told the next step and the next place to click to achieve your goal.

Cura

Cura is the software that comes with the 3D printer from ultimaker and it is a very simple and user friendly program. At first glance it hides many of its advanced features under the "advanced" settings. This makes the interface clean and simple. When you mouse over an option, a tooltip pops up which lets you know what this setting does. Once you load your 3D model in to Cura it shows up and the process of transferring it to an SD card is very easy, one click of a button and the file is transferred. There are also some settings that allow you to scale the model up or down as you want. These settings come in handy if you would like to see a smaller version of your print before you commit to the longer print time of the larger model. Additionally, the software helps you to choose certain settings such as support structure and whether to use brim or not for the print.

Software on the Ultimaker 2

The software on the Ultimaker 2 itself is quite easy to use. It features an LCD screen and a dial that you turn and press to choose from a menu. After inserting the SD card your print can be found under the "Print" option, one can change the print material under the "Material" option and under maintenance there are many functions that can prove very helpful when the printer clogs or other similar issues. These functions includes manually heating the printer head, manually extruding the material and more.

GravoStyle

GravoStyle is the software that comes with the Gravograph. It is a program that allows you to import many image file formats and plan files for cutting patterns. Also, the program allows you to draw your own patterns with squares, circles and all many different shapes already built in to the program. The size of the material is defined upon entering the program where it asks you to type in dimensions for the material and safety margins. These settings are carried into the area where you import your pattern and makes it easy to make sure the cut is placed correctly on the material. There is a very useful function that lets you prioritize what parts the cutter will cut first, second, third and so on by coloring parts of the print in different colors that is prioritized differently. This can be particularly useful if you want to make a hole in the product and want to make sure it cuts the inner hole first, so that the workpiece does not move when it is cut loose from the material. When entering the final stage there is a clean interface that lets you customize the cut settings for each of the colors and it lets you pick a material profile which carries with it a standardized set of settings for laser effect and travelling speed.

SRP player and Vpanel for the Roland MDX-540

When the model is done you need to plug it into SRP player. This is the software that will allow you to define the size of the workpiece that you have put into the machine, confirm size, orientation and other details concerning the milling process. After this the software will create a tool path for the tool to follow during the mill. After this is done the interface for the machine controls (the Vpanel) will open and you can start the mill and be allowed direct access to tool speed, pause, resume and manual tool movement functions.

These digital resources vary in their simplicity and

Digital tools handy in a makerspace

Thingiverse / Instructables

If you aren't very steady in the CAD -software or the parts you need are not highly customized the chances are someone else has already made them. And if you are lucky they have also shared them, there are several communities on the internet devoted to sharing own designs and teaching making skills. www.thingiverse.com and www.instrucables.com are two such sites. Thingiverse is the site that is more directly directed towards the tools available in a makerspace, this site allows people to upload and share their 3D models along with pictures of the finished product and tips to printing, machining or assembling. From this site you can download products from a large catalogue of uploaded designs. These files are not locked,

which means they can be edited to fit personal preferences or needs. You can also give feedback to the uploader to tell them what you think. Instructables is aimed at a broader audience. It has many types of guides, not just relating to making things in a makerspace. Here you are asked to finish the sentence "Let's make____" in the search option, and it captures the essence of the site well. You will find guides for everything from food to how to make your own costume and how to make 3D printed, milled or laser cut objects. In this environment you will find a multitude of tips and tricks about different making software and how to make your own files or simply download complete designs.

123D Make

This is a complementary tool for the laser cutter developed by Autodesk. 123D make lets you import a 3D model and it will convert the 3D model into a combination of 2D elements that you can put together to make a 3D model. There are several ways to make 3D models from this tool and it complements the 2D-only cutting of the laser cutter very nicely.

Findings from making the products

Material choice

Material choice matters for some products and the mill and laser cutter had the widest variety of them. The mill can machine many materials, among which are wood and nylon that represent two materials of different properties. They are both relatively soft, the wood is cheaper, but the nylon is a uniform material without branches like the wood. This makes it easier to optimize the milling speed to what the tool can take since the material will not have different densities. This also affects the chip from the material, with a uniform material it is easier to get constant chip that removes itself from the tool, the shorter more irregular chip from wood will easier stick to the tool so that it has to be removed manually.

Other dimensions of material choice include testing mechanical parameters of the finished product, such as strength or flexibility. For this purpose, a material as similar to the material the finished product will be made in should be chosen.

Placement and fastening

The material in the laser cutter was often used before and one had to find an area which had enough unused material for the pattern one wanted to cut. When the gears were being cut there was an incorrect assessment of how much space was needed, which resulted in one of

the gears having a couple teeth shaved off by the lack of material where the laser was cutting. To avoid waste of material one should double check the placement of the material according to the software.

The mill requires one to fasten the workpiece to the workplate so the machine will not send the product flying. This can be easy or it can present some challenges. The gears were fastened with clamps and nothing was done about the design, which resulted in the machine ripping the gears loose before all of the material was machined. When observing a subject using the mill, he altered the design of the CAD model to have two parts stick out to serve as anchors. He screwed the workpiece to the plate and it came out as one piece as well, but with two rods holding the product to the frame, which he could easily break off and sand away.

Risk of favorite machine

Once a machine was getting familiar, it was easier to gravitate towards using this machine for the next crafts as it was a more known factor. This happened in the disfavor of the mill, where the two other machines were given more attention. This might stem from many reasons, the mill seemed more frightening, boring or simply not as "cool" as the two other machines. The best explanation is a combination of the three.

Dare to repair

When one starts getting the hang of the different machines and understand them, one will understand that repairing small problems are not so hard. This is a good confidence booster and helps with the general understanding of the machines.

Troubleshooting

3D printer

Troubleshooting the 3D printer was a good method of learning. Things to troubleshoot was e.g. what do you do when no material comes out after you have started the print? This could be from many reasons it turned out, for example the feeder could have grinded into the material and stopped feeding or it could be from a clog in the print head which itself could have different reasons ranging from too high or too low a print temperature to pollution from a previous material.

Figure 21: Pollution from a different material, cleaned using the «Atomic method»

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(Figure 21). The polluted pieces of printing filament in Figure 21 are pulled out using the "Atomic method" of cleaning. In this method the print head is heated up to the maximum of 260°C, filament is inserted, then the print head is cooled down to below printing temperature before the material is pulled back, this brings pollution with it since the material is allowed to seep down and then solidify around the pollution.

Support structure may need to be activated, in the case of "Being the actor" this was a point of troubleshooting, as the printer started printing mid-air and the print had to be restarted. It felt good to be able to solve this through a short troubleshooting session, which is a confidence booster. The support structure that was used with the knight was "Lines" as this is a structure that is more easily removed it suits weak geometry better, the arms were quite thin and could break quite easily if one had to apply a lot of force to remove the support. Printing with "Lines" support structure means that the printer will put parallel lines up to the point the print starts and use them as a foundation for continuing the print. The alternative support structure is "Grid", which prints a grid instead of lines, this is a stronger and harder to remove structure

Laser cutter

For the laser cutter, the troubleshooting mostly involves finding the correct power and speed the laser will use for cutting. This varies for plexi glass, plywood, cardboard and other materials. A good help is given by the software, but sometimes you may have to tune it further to get optimal settings for the thickness you are using. For this kind of troubleshooting it helps to narrow down the problem with questions like "Is the material catching fire?" Try turning up the speed to avoid the laser spending too much time in one place. Or you could try to turn down the power and increase the number of times the laser will trace the pattern to see if this will help.

Mill

For the mill there were a couple issues that one could look into, one is mentioned under material choice and concerns milling speed. Finding the proper milling speed for a non-homogenous material can be hard and requires listening to the machine and constantly assessing whether the density of the material is changing.

Another problem is what to do if the mill is overloaded it can be hard to get the tool out. This was a point of struggle for the first two mills, the solution became to use two wrenches to loosen it and remove the tool itself before restarting the mill.

Barriers of engagement

Here, the barriers that was experienced and observed will be presented. The different barriers will be grouped into socially related barriers, skill related barriers and safety related barriers. The presentation of each barrier will be a short description of what is meant by the name it is given.

Seven interview subjects provided a total of 240minutes of recorded interview. In this case all things that they expressed explicitly as something that would prevent them from using the machines or something that would make the experience of using them harder or more unpleasant would be considered a barrier.

Social barriers

Fear of making a fool of oneself. This is the fear of embarking on something you do not (yet) possess the skillset to do skillfully especially when other people are watching, in fear of them judging you or thinking less of you in some way.

Time cost for other people. If a mistake is made or a print set in motion with the wrong settings, the next person in line might have to wait for a long time.

Both fear of making a fool of oneself and not wanting to inconvenience other people were barriers that hindered engagement with machines in the beginning of the "Be the actor" part. Obviously it is hard to tell what people are thinking, but through their behavior under observation, one can draw some conclusions. The first subject under observation while using the mill stopped after struggling with the fastening for a while and asked "Are you waiting for this machine?". After replying "No, no, just thinking", he said "Good" with a smile and turned back to what he was doing for a while. This at least shows he was considering the other people in the makerspace and their need for the machines, he seemed relieved when he was lifted of time pressure.

Incompetence. This barrier relates to the feeling of inadequacy, the feeling of being not good enough or not having the skills required to operate the machines.

Ultimaker software and functions. The uncertainty related to unknown computer software

Changing material: When you either run out of material or want to use a different one than the person who last used the machine, you will have to change. Unknown process for the novel user.

Cost: The 3D printer feels like an expensive piece of equipment for a novel user, one thought that occurs is that failing can be expensive. Either by using a lot of material or breaking the machine so that new parts or repairs are needed.

Gravograph software and functions. Uncertainty related to unknown computer software

Roland mill software and functions. Uncertainty related to unknown computer software

Expensive to replace broken tools and sensors. Sensors are finely tuned and rotary cutters are precision tools

Long and complex set up routine. Makes "doing it again" a bigger barrier if the machining fails.

The first barrier mentioned here, Incompetence, is a broad one that in a way encompasses all of the other ones. These barriers were encountered when encountering a new action point with the machines, one that you had not encountered before, or even before you start you encounter these as your expectations of what will be the hard part of operating the machines. The ones considering the waste of material or fear of breaking the equipment were also observed as the things people asked about the most often. The second observed subject of the mill asked a nearby helper two times "Do I just press start now?" and was watching in suspense as the mill lowered the tool towards the sensor to check what tool it was holding. He breathed a sigh of relief when it slowed down and when it started reversing after the measurement was completed. This shows that he was concerned for the equipment and did not trust his own experience with the machine, which proved a barrier for him.

Safety related barriers

3D printing hand injury: The Ultimaker 2 has an open design where there is enough space to put your hands in to remove chip from the print as it is going. A novel user might wonder if this is something that has to be done to heighten the quality of the print. And if so, wonder if there is a risk of hand injury when doing so.

3D printing burn: The Ultimaker operates at high temperatures (about 200°Celsius for PLA, and higher for some other common materials). A novel user might have some reservations concerning these high temperatures and wonder the risk of getting a burn.

Laser cutter safety safety. The laser cutter uses a laser to cut through objects and a novel user might worry about eye damage.

Laser cutter fire. Cutting with a laser produces a lot of heat which can set the material on fire.

What do I do if the material in the laser cutter catches fire? How to handle a situation where a fire breaks out inside the machine.

Cutting injury, mill safety. The mill is a machine that uses rotary cutting tool, this induces a caution towards cutting injuries.

These barriers are the ones concerning fear of injury or injuring others. While Being the actor many reservations was felt. When you see the screen of the 3D printer saying that the printing temperature will be 220° C or higher it is only natural to be reserved about putting hands into the printer for removing material, the print or a clog, especially if one is uncertain of how this machine works. This overly cautious behavior was observed with the laser cutter where one subject would consistently turn his back on the cutter when it was working. When asked about this afterwards he said that he was trying to avoid eye damage. While it is certainly good to avoid staring directly at the laser for prolonged periods, this provides a barrier that kept this user from observing the process and having the possibility to cancel and alter settings if it was going wrong.

Interviews

The findings form the interview were held up against the findings from the action research to see if it would strengthen or weaken the results, it proved a good complement to the research. The results will be presented here with the same clustering of barriers as earlier, Social, Skill and Safety.

Socially related barriers

A total of 2 different social barriers mentioned

Socially related barriers were mentioned 2 times

Average of 0,3 barriers per interview subject
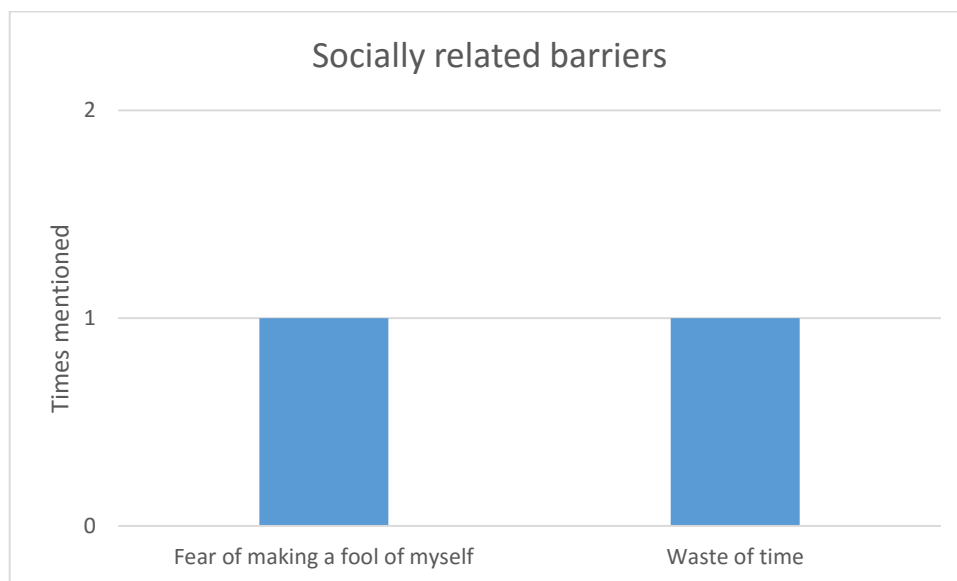
Figure 22: Social barriers from interview

In the interview, two participants mentioned socially related barriers. When asked about what they meant with these the one participant said that she had a presentation anxiety which gets worse if other people are watching. In a makerspace she said there would be people watching her projects and it would be uncomfortable to not be able to work in private. Another participant mentioned the wasting of time, by this he meant that others might get annoyed with him if he used too long or had to do multiple crafts if they wanted to use the machine. Figure 22 shows the distribution of Social barriers mentioned.

Skill related barriers

A total of 6 different skill barriers mentioned

Skill related barriers were mentioned 14 times

Average of 2 barriers per interview subject
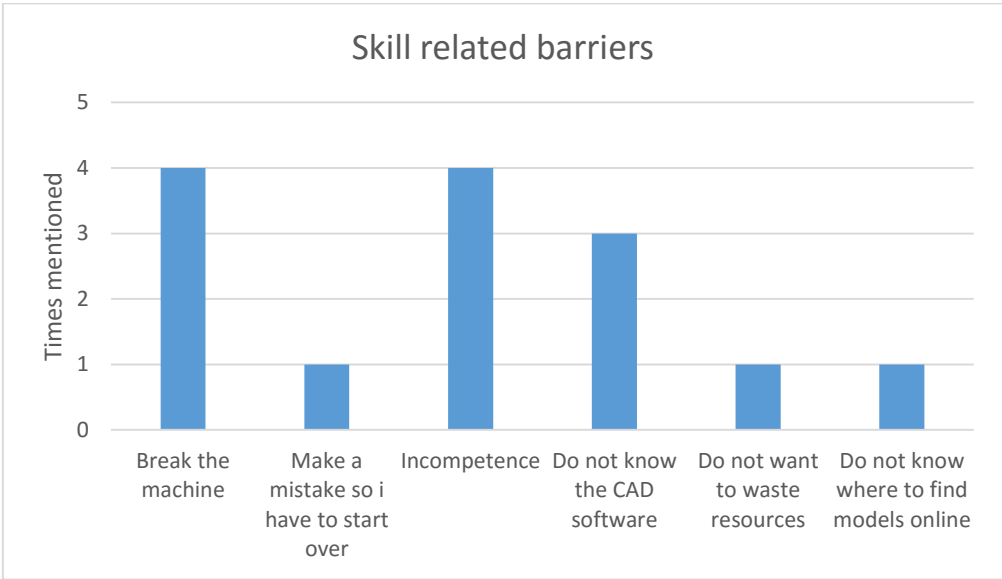
Figure 23: Skill related barriers from interview

This was the biggest bulk from the interviews. The most mentioned barriers from the interviews was a fear of breaking the machines as a consequence of improper use, this was emphasized by the fact that the novel users that was interviewed view the equipment as expensive. The general lack of experience in a makerspace "Incompetence". One of the participants said "I don't know where to begin", which captures this point well. The last of the most mentioned was a lack experience with CAD software which was something the participants who mentioned it had heard you had to be good at to make proper models for the machines. The last three barriers were mentioned once each and concerned the wasting of time or resources as a following of the lack of skill. Also, one said that he did not know where to find other people's design since he could not make them himself in a CAD program. Figure 23 shows the distribution of Skill related barriers mentioned.

Safety related barriers

A total of 2 different safety barriers mentioned

Safety related barriers were mentioned 3 times

Average of 0,4 barriers per interview subject
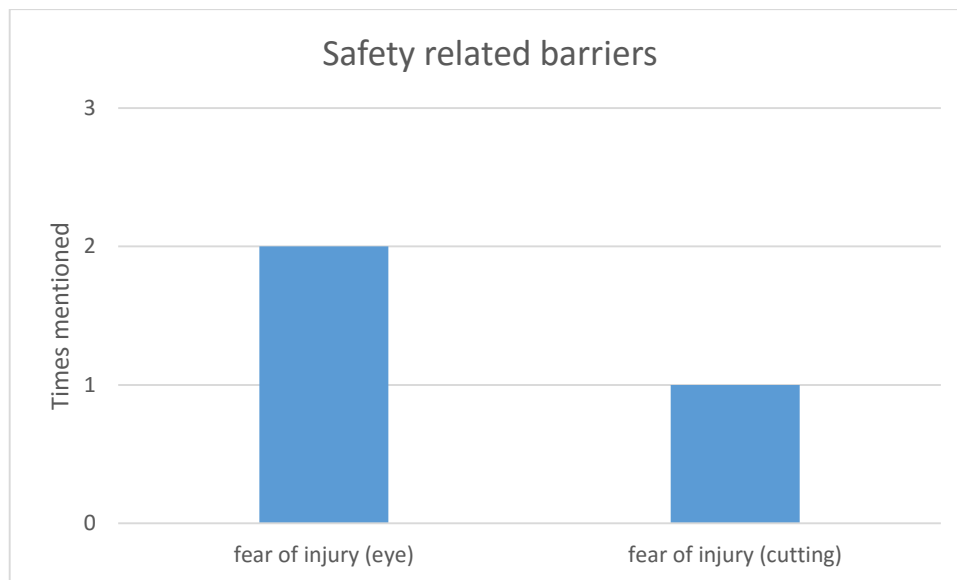
Figure 24: Safety related barriers from interview

The safety related barriers were concerning damage to oneself, when asked about the fear of breaking the equipment, the participants answered that they thought in a more economical sense than safety. The fear of eye injury is connected to the laser cutter, which by its very name induces fear of eye damage in some cases, one of the participants explained that he had always been told by his mother that he must never light anyone in the eye with a laser pointer, and when he heard that a machine used a laser for cutting he thought "This must be even more dangerous for the eye". This was also observed in the observation part where one subject would face away from the laser cutter from fear of eye damage. Fear of cutting injury was connected to the mill, the participant said the he had heard about the mill and the lathe in the same context many times. And the images of injuries by the lathe he had seen were really deterring and had really made an impression on him. Therefore, he always thought about injury in the same sentence as these two machines. Figure 22 shows the distribution of Safety related barriers mentioned.

Emotions related and not related to makerspaces

The participants were asked to choose five emotions they related to a makerspace and five they did not. This was meant to give a general idea of the novel user's expectations towards a makerspace. The result of this action point is presented here.

> Most commonly related emotion: Optimism (6)
>
> Most commonly unrelated emotion: Hatred(7)
>
> Least related emotion: Surprise, Goodwill, Confidence, Annoyance, Confusion, Nervousness, Wonder (1)
>
> Least unrelated emotion: Sadness, Boredom, Pity, Cowardice, Dispair, Envy, Relaxation (1)
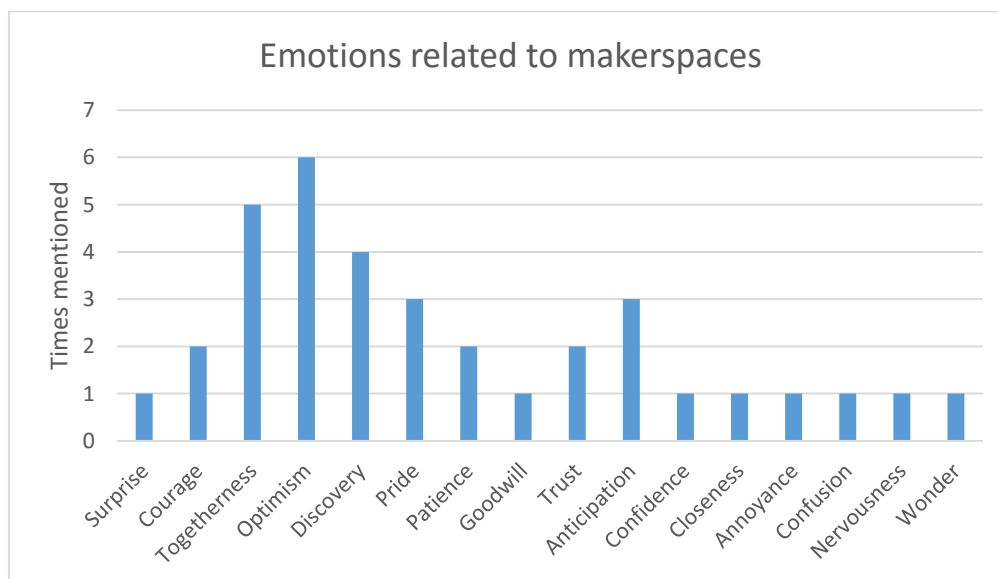
Figure 25: Emotions related to makerspaces

As we can see the most related emotions are ones that can be considered positive, such as Optimism, Togetherness, Discovery and Pride. The least related emotions are a mix with some positive and some that can be considered negative, like Annoyance and Confusion. Figure 25 shows the distribution of emotions related to makerspaces by the participants of the interview.
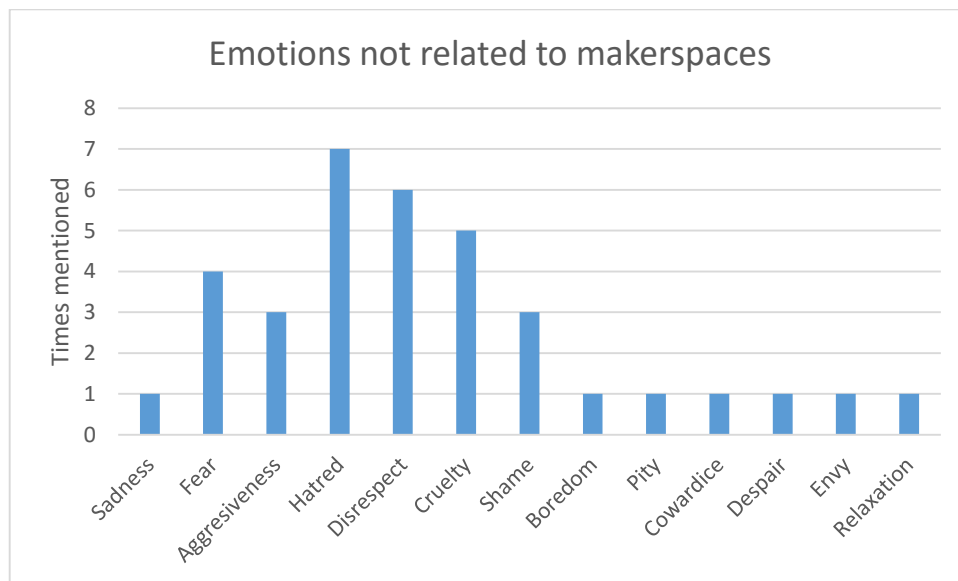
Figure 26: Emotions not related to makerspaces

The emotions the participants did not relate to makerspaces the most were very negative ones like Hatred, Disrespect and Cruelty. The ones that they did not relate the least often were variations of negative emotions like Sadness, Boredom and Pity. But also Relaxation, which was said to be unrelated because the interview participant said that she believed there would be something happening at all times. Figure 26 shows the distribution of the emotions the participants did not relate to makerspaces.

Other findings from the interviews

Scariest machine

At the end of the interview the participants were asked what they thought would be least appealing machine. The mill got six out of seven votes from this question with as much as four of those six calling the machine scary in their explanation of the choice.

On the other hand, the 3D printer got the most votes for most appealing machine with four out of seven picks. These participants said that the 3D printer had the coolest technology and it seemed the easier one to use, so it would be a good place to start.

Conclusion of findings

TRIZ implementation from action research

From what was learned in the "Be the actor" part, it is clear that the different machines have some strengths. These strengths are not immediately clear to the novel user, and therefore it can be suggested to put these in to a system where the same principles as TRIZ is built upon are applied. If you have a challenge or a problem, TRIZ is a system of suggestions that suggest a way to solve your problem based on your input. This can also be applied in a similar way to the machines, different parameters of a craft for geometry requirements, strength/material requirements, production time and other similar requirements for the product. What follows is a suggestion for a type of tool to help novel users choose what machine to craft an object with along with some examples for the tool.

The physical result of the "Be the actor" part was 19 unique prototypes; these have been analyzed along with the process of making them. Similar prototypes made in different machines are defined as different and unique. E.g. in this case the three bottles count as three unique prototypes. A total of 35 prototypes were made between the three machines, which gives each prototype an average of 1,8 crafts.

The distribution of the prototypes can be seen in Table 2 The recraft rate is a measure constructed from the number of unique prototypes and number of crafts in a specific machine. This tells the average amount of times a prototype was made in that specific machine, rounded to nearest tenth.

Table 2: Total amount of prototypes made

Machine	3D printer	Laser cutter	Mill
# of unique prototypes	6	8	5
# of crafts	13	17	5
Recraft rate	2,2	2,1	1

The suggested system for helping to choose appropriate machine can be presented as follows. One category is Geometry. From the prototypes that was made it is clear to see that a 3D

printer is capable of many types of geometry, from a hollow bottle to a figure of a knight. The laser cutter is at the other end of the spectrum for this criteria, it shines when the object consists of straight surfaces and right angles. The mill has a more varied field of use and can be used from simple crafts to more advanced, some of the more advanced geometries, would however require more changes of the fastening than would be practical. In addition to this, the mill has been placed lower than the 3D printer because the printer was able to print more complex structures than the mill. A suggestion for deciding what machine to use based on geometry is shown in Table 3.

Table 3: Suggestion for machine choice based on product geometry

Geometry	Simple	Medium	Complex
3D printer			X
Laser cutter	X		
Mill		X	

All of the machines were able to create a model with overhang, but the 3D printer and the mill had distinct criteria to fulfill before doing so. The 3D printer would need support structure and the mill would need several fastenings. The laser cutter very naturally lets you assemble a product from different parts, which makes this a trivial issue (Figure 10). A table showcasing this is shown in Table 4.

Table 4: Suggestion for machine choice based on product overhang

Overhang	Yes	No
3D printer	X (requires support structure)	
Laser cutter	X	
Mill	X (if turned and fastened again after start)	

If time is a concern for the production, a table such as this (Table 5) could be considered.

Table 5: Suggestion for machine choice based on production time

Time pr. Production operation	Low	Medium	High
3D printer			X
Laser cutter	X		
Mill		X	

More specific tables, such as Table 6 could be made to highlight weaknesses of one specific machine.

Table 6: Suggestion for machine choice based on inside corners

Sharp inside corners in your design?	Yes	No
3D printer	X	
Laser cutter	X	
Mill		X

Strength is a hard variable to pinpoint, but the laser cutter and the mill seems to generally have a higher material strength than the 3D due to their materials. The 3D printer can print in a few different materials, which do have somewhat varying characteristics, they are however all plastics and suffer from being brittle. The laser cutter can cut in materials from cardboard up to ceramics and coated metals, the mill can also machine different materials from foam materials, wood, nylon and some metals. This gives them a higher flexibility and higher top strength than the 3D printer. The mill is set at the top due to the one-part uniformity that the mill often exhibits, which means that there are no weak points contrary to the laser cutters

products which are often assembled from different parts. This strength consideration is shown in Table 7.

Table 7: Suggestion for machine choice based on strength required

Strength required	Low	Medium	High
3D printer	X (can be increased by increasing fill %)		
Laser cutter		X (highly dependent on material)	
Mill			X (dependent on material)

Another example of a more specified table to explain the weakness of a specific machine can be for what the machine is unable to achieve, but can be achieved by post-processing the product. The example here is the smooth elevation transition which is hard to get in a laser cut product. The product could however be produced and treated with sandpaper or a file afterwards to gain a better surface quality in this respect. Table 8 shows this example.

Table 8: Suggestion for machine choice based on elevation resolution required

Smooth elevation transition required	Yes	No
3D print	X	
Laser cutter		X
Mill	X	

Barriers

In the interview, the participants were asked to give a short explanation of each barrier along with an assessment of how "high" this barrier would be, how hard it would be to overcome. If one wants to make the novel users interact with machines by their own will, one would have to help them overcome these high barriers first.

The two social barriers were said to be high barriers, particularly the "making a fool of myself".

The skill barriers were variable in how high the participants perceived the barriers to be, but the ones that were mentioned most often, "Incompetence", "Breaking the machine" and "Not knowing CAD software" were said to be high barriers, while the less mentioned ones "Make a mistake so I have to start over", "Do not want to waste resources" and "Do not know where to find models online" were assessed as low barriers.

The safety related barriers did not score very highly, the participants were adamant that with some training or coaching and practice these would disappear by themselves.

The high barriers that was discovered from this interview section do correspond with what was experienced and observed in the action research part. In the observation where one participant asked for help and the other did not when using the 3D printer, it can be argued that there were two types of barriers blocking the users path. One was the general incompetence that made the user unsure what was the next step and the other was a social barrier that one overcame and the other did not concerning inconveniencing others by asking for help. During the "Be the actor" part of the action research these barriers were also experienced, the feeling of not knowing the machines or the process and not knowing the next step can be a powerful inhibitor.

Thus it is concluded that a method for learning should be focused on overcoming these barriers and being aware of when one overcomes them to build confidence

Discussion

Teaching in makerspaces

Now that we know more about the novel users' experience in a makerspace through the eyes of several novel users, what can this knowledge be used for? From this we can structure a mode of teaching that takes into consideration what the user sees as the real issues. We can develop a teaching mentality that facilitates confident makers. This is a similar mode of teaching to what Parker suggested in his article on skills needed in a makerspace. Instead of being taught by a mentor, we suggest a more peer based way of learning. This is not contradicting other teaching methods, but can serve as a supplement to an arsenal of methods.

The findings in this paper point towards a method finds the novel user's highest barriers and helps to lower them as the most beneficial method of learning to use the machines in a makerspace. Generally, what seems to be higher barriers are the ones that concern oneself and the lack of skill with machines or software and the barriers concerning social behavior and others' perception of oneself. This seems to correspond well with what Hull said in *Understanding Librarians*. The lack of skills with the machines makes the machines have unknown factors that can be scary to the novel user. These unknown factors can induce the fear of 'Losing face', or "Making a fool of myself" as it is called in this paper.

As shown by the manuals for the different machines and Hlubinka, Dougherty, Thomas, Chang, Hefer, Alexander and Mcguires *Makerspace Playbook*, a large focus of the teaching literature and material for the machines focus on safety. This is, however, not what the novel users sees as the big barriers, and does not help much to ease their fear of interaction with the machines. So what *would* help? How *should* we structure a teaching session?

An early teaching session should be kept simple to avoid 'information overload', another barrier that Hull mentions. One should show how to operate machine safely and tackle high barriers one at a time. Encourage people to seek help from each other. Most important however is discovering the specific novel user's barriers and dealing with those barriers, not just general ones.

Here is a suggestion for the first teaching session with the laser cutter. During the entire session it is important to keep a dialogue with the novel user and try to understand what they see as barriers. One can start by showing the novel user an online resource like www.thingiverse.com and let them find a design they like, then download this and put it on a

drive. After that one should show how to import the design and select the settings necessary. Before the cut is started, one should mention material choice and what consequences it might have as well as some basic safety concerns. Let the novel user put the material in and press start. It is important that the novel user is being made aware of what barriers he faces and overcomes to build confidence. After the cut is done some digital tools should be mentioned, where and how to design your own design and other aids for the specific machine. Ideally one session is enough and an interest has been sparked, at this point the novel user should be left alone to explore and overcome barriers by himself. Another important factor to this method is that the atmosphere in the makerspace is one that is accepting of failure after an honest attempt, this atmosphere can be emphasized by pictures or quotes such as the one shown in Figure 27
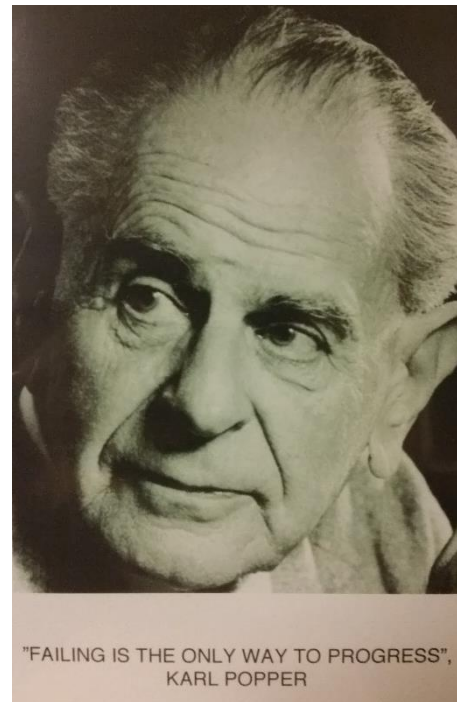

Figure 27: Karl Popper quote

There is a risk of developing a favorite or least liked machine, as was done while being the actor in the action research, this can be seen in the amount of prototypes produced with each machine, the prototypes made in the mill were taken as 'good enough' since the machine seemed scarier for the actor than the other ones, where a prototype with flaws might quicker be judged as not good enough and try again. It is important to make sure the novel users give all the machines a good try.

"Play is a *state of mind*, rather than an activity" (Brown M.D.: *Play: How it Shapes the Brain, Opens the Imagination and Invigorates the Soul*, p. 60)

What to make of these emotions?

The emotions the participants picked quickly revealed a pattern, the emotions the participants related to a makerspace were mostly ones that can be considered positive, such as optimism, togetherness and discovery. These are ones we can tap into and try to emphasize to make the general atmosphere of the makerspace better and more in line with what the novel users want. The interview participants suggested activities like workshops and team building exercises to discover, share experience and build bridges that would also serve as barriers to the negative

emotions they said they did not relate to the makerspace. These negative emotions are ones that the participants said they just did not want in their environment. These were emotions like hatred, disrespect and cruelty. If the makerspace becomes an arena filled with these emotions, it will not be creative and constructive environment. The tools they suggested for making sure that these emotions would not be a part of the makerspace was mainly the same ones as for keeping the positive emotions around, but with a couple of additions. They wanted clear communication to be the norm, make it known to the concerning person at once if you have a problem. Another highly requested feature was a person with a mentor role to be available, this could be in the form of experienced users or a person whose job it was to help novel users. This might not be so easy to implement, but it brings us back to learning the machines.

The strengths and weaknesses of the machines can be presented in many ways, but in reality the design can be changed or the making process can be tuned to fit the product, for a mill the fastening can be changed multiple times before the product is done, this enables the mill to make designs that would otherwise be impossible for a three axis mill, the laser cutter can make parts in many different thicknesses dependent on the material which can be processed afterwards to the characteristics you need. For example, grinding down the leveled elevation of stacked slices for a smoother transition with sandpaper or a file. The 3D printer takes a long time to print something, but the time can be reduced by reducing fill percentage, if the print does not require much strength, the outer shell thickness can also be reduced for a faster print. The other way also works, if the print needs more strength, one can increase the fill percentage or shell thickness. To a novel user however, these are not very easy options. Instead, we can suggest what machine they should use for their product depending on different variables. This can be seen as "a novel user's TRIZ for selection of production method" and will benefit from restricting it to few machines, once again to avoid information overload.

The motivations for using a makerspace can be many, and is not a topic that is touched upon a lot in this paper. In this case the actor has been forced to learn through the writing of a master's thesis, this is a powerful motivator since the consequences of backing out are quite severe. Other novel users might have a less powerful motivation and as a result might back out earlier. The hope is that this method will make such a motivation unnecessary because of the very nature of the method, where you identify what the problem is for each novel user and help them overcome it.

So, reskill or deskill?

When considering the barriers we have uncovered and the way we have chosen to overcome them, it should be safe to say that reskilling is a big part of this paper. The passive consumers can be seen as the novel users who are being brought in to the process of making. This thesis makes an effort to raise the user to the level of the machine in a positive way, which supports reskilling. This also does not take anything away from the machines or the experienced worker. The experienced user will be able to achieve more in his usage of these machines than the novel user, which is how it should be. To avoid deskilling one should have a high roof for what the machines are capable of, this keeps the machines interesting and the will to learn around for longer as well as it lets skilled users use their potential.

This paper seeks to push the "debate" mentioned in the "Background" chapter in the favor of makerspaces reskilling the novel user instead of deskilling the experienced user.

Method criticism

This part seeks to increase awareness of the way that this thesis work has been conducted and what limitations and flaws its methods had in its execution.

Student environment

This research has been conducted in a student environment where all the observed subjects and interview participants were students. Novel users can be found in the industry as well, which provides another arena of research. The barriers may vary in these situations, but in essence the method suggested in this paper should be applicable to most situations, because it is based on the principles of discovering personal barriers rather than overcoming specific barriers.

Interview

One should always consider that the data one is looking at might be incomplete. It might even be incomplete in a particularly biased way, in this example it is pretty clear that the pool of interview subjects are people who are interested in makerspaces and learning the skills required to excel in a makerspace since they are a part of an establishing makerspace's staff. As a result of this, the amount of barriers and the severity of them are probably lower than if we would choose random interview subjects from the population. As of right now, choosing people who are interested in learning by their own initiative might be the right audience to

interview, but as with most tools, makerspaces are going to get more and more integrated into teaching. This means that for the future, if we are going to give all an equal chance to get to know the equipment and build a confidence in a makerspace we need to look at a broader sample than is considered in this pool of interview subjects. We need to consider what is keeping novel users without an abundance of interest in learning the skills required in a makerspace from using these machines.

Some of the barriers that was mentioned had just one mention and a was assessed by that participant to be a high barrier, while this was certainly true for that individual and should be taken into assessment for her, this provides a weak ground for generalizing that this is an important barrier.

Some barriers might not develop before the participants are allowed to use the machines, the fact that this interview was held with complete novel users might lead to missing some barriers that would have been present for the participants if they were allowed to use the machines first.

Conclusion

In this master's thesis the focus points have been to explore what is preventing novel users to be able to use machines in a makerspace and how to better teach novel users use these machines. The research method has been triangulating by three different methods, qualitative interviews, observation and being the actor. The analysis of these methods have been to take notes underway during all research methods, the interview was recorded as well and has been listened over again to make sure the information was the one the participants gave. These notes have been processed and generalized into the barriers and strengths and weaknesses presented in the findings section. The findings were found from seven interview participants, six observation subjects and 19 unique prototypes (33 total as some were of the same product) made as a part of being the actor. Nine of these 19 prototypes were made as part of "Three prototypes in three machines", then another prototype was made in the three machines to further emphasize strengths and weaknesses in the different machines.

We contribute with method of teaching novel users how to use machines in a makerspace and the atmosphere of a makerspace in general. This method builds on existing literature as well as adds in the new factor of mapping out each individual participant's barriers towards using the machines and visualizing them for the novel user when he or she overcomes them. The first part of the method supports existing literature with the findings that novel users want to have fun and discover in a makerspace and the method applied should be to support this. The second part consists of the new part of exploring personal barriers and the parts that supports existing literature of building confidence and having help or coaching.

Additionally, we contribute with a suggestion of a new type of tool that can serve as an aid for the novel user in choosing what machine to use for his/her product. This tool employs the principles of TRIZ and should serve as a system where the novel user can input his/her products needs and get an answer for which machine is more suited for this specific product.

This is an important topic of research because the makerspaces are here to stay and the democratization of them is ever expanding with more and more novel users gaining access. As Rivas shows makerspaces is a good tool for teaching young children the art of making. This application of makerspaces will only expand in the years to come, where more and more young children will have access to different levels of makerspaces in schools. This is why finding a proper method of teaching the use of the machines in a way that creates confident users is important.

Suggestions for further work

The next step would be to test this method out more. For this purpose, we suggest making a larger scale interactive interview in the proximity of the machines where the participants are allowed to use the machines and can tell about the experience in ways that the interviewer could consider to improve the method. This could also be made into a workshop where it is tried out in a larger scale.

Testing the method in different settings would also be an interesting topic to research. As mentioned in the "Method Criticism" part a testing in the industry would be good to see if it is applicable to other settings than for students. And if not, improve the method towards industry as well.

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Attachment A: Inteview guide

Conscent for audio recoring and usage of findings in masters thesis

Name

Age

Line of study

(gender)

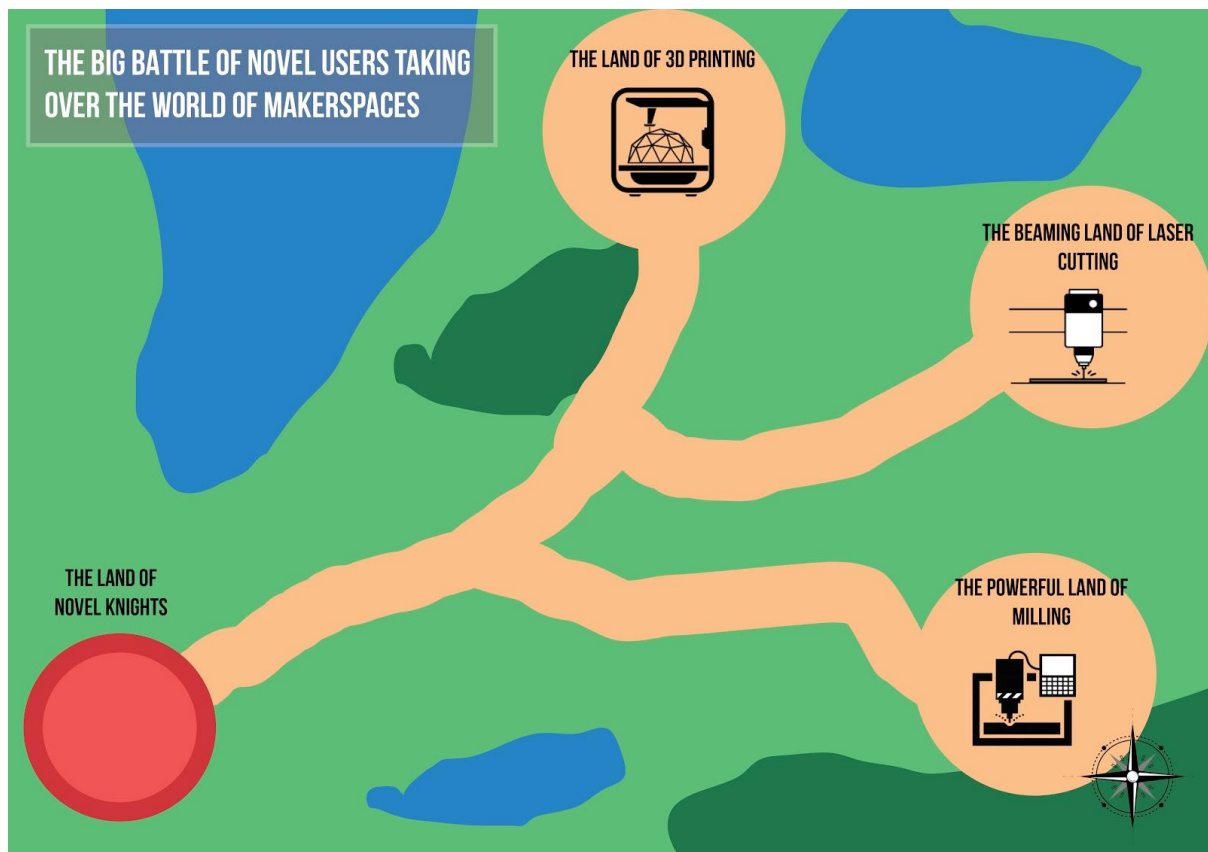What are your expectations to a makerspace?

Previous experience with either machine?

An Introduction to maker space and brief presentation of laser cutter, mill and 3D-printer

The Interview Game

THE BIG BATTLE OF NOVEL USERS TAKING OVER THE WORLD OF MAKERSPACES

THE LAND OF 3D PRINTING

THE BEAMING LAND OF LASER CUTTING

THE LAND OF NOVEL KNIGHTS

THE POWERFUL LAND OF MILLING

Introduction:

Makerspaces are popping up all over the world allowing novel users to take over machines that earlier was designed for machine workers and engineers. However the challenge remains on how to teach novel users the skills needed in a makerspace and define what barriers are present that keep people from building prototypes.

Round I:
Imagine that a makerspace was build at IDI including a 3D-printer, a laser cutter and a mill?
What are the barriers for you to use the machines?
2 minute brainstorm
Explain to the interviewer

Round II:
Imagine the makerspace at IDI as a whole system including people, machines, tools, projects, prototypes etc.
What kind of emotions would you relate to this makerspace pick 5 of the cards (3 minutes).
What kind of emotions wouldn't you relate to this makerspace pick 5 of the cards (3 minutes).

Explain.

List of emotions:

Fear	Nervousness	Security	Respect
Disrespect	Privacy	Togetherness	Appreciation
Envy	Goodwill	Love	Hatred
Hope	Despair	Confusion	Pride
Shame	Closeness	Distance	Patience
Tolenrace	Relaxation	Stress	Discovery
Surprise	Confidence	Optimism	Agressiveness
Happiness	Satisfaction	Sadness	Wonder
Courage	Cowardice	Pity	Annoyance
Anticipation	Trust	Boredom	Cruelty

What is the time aspect in these emotions change over time?

Round III:

Now imagine you should come up with some tools/powers to overcome these challenges?

2 minute brainstorm

Explain to the interviewer. Why are these good ideas?

Which one of the machines would you try out first and why? Which want do you "fear" the most?

Attachment B: Risk assessment

Kartlegging av risikofylt aktivitet

Enhet: Department of Engeneering design and Materials   **Dato:** 26/5-16

Linjeleder:

Deltakere ved kartleggingen (m/ funksjon): Martin Steinert, veileder. Matilde Bisballe Jensen, veileder. Petter Ildgruben Birkeland, student.
(Ansv. veileder, student, evt. medveiledere, evt. andre m. kompetanse)

Kort beskrivelse av hovedaktivitet/hovedprosess: Teste produktutviklingsverktøy på TrollLabs, hovedvekt på 3D-printer, Laser kutter og fres.

Er oppgaven rent teoretisk? (JA/NEI): **NEI**   «JA» betyr at veileder innestår for at oppgaven ikke inneholder noen aktiviteter som krever risikovurdering. Dersom «JA»: Beskriv kort aktiviteten i kartleggingskjemaet under. Risikovurdering trenger ikke å fylles ut.

Signaturer: Ansvarlig veileder: Martin Steinert   Student: Petter Ildgruben Birkeland

ID nr.	Aktivitet/prosess	Ansvarlig	Eksisterende dokumentasjon	Eksisterende sikringstiltak	Lov, forskrift o.l.	Kommentar
1	Bruk av trollLABS makerspace	PIB		Brannslukkinsapparat, brannalarm		
1a	3D printing	PIB	Maskinens brukermanual			
1b	Bruk av laserkutter	PIB	Maskinens brukermanual	Dekke med avsug		
1c	Bruk sammenføyningsmidler	PIB	Sikkerhetsdatablad og produktets brukermanual	Sikkerhetsdatablad		
1d	Bruk av fres	PIB	Maskinens brukermanual	Dekke med detektor		

NTNU

HMS

Kartlegging av risikofylt aktivitet

	Utarbeidet av	Nummer	Dato
	HMS-avd.	HMSRV2601	22.03.2011
	Godkjent av		Erstatter
	Rektor		01.12.2006

			Produktets brukermanual
1e	Bruk av skjæreverktøy	PIB	
2	Arbeid utført av andre	Ukjent	

Risikovurdering

Enhet:

Linjeleder:

Dato:

Deltakere ved kartleggingen (m/ funksjon): Petter I. Bukland (student)
(Ansv. Veileder, student, evt. medveiledere, evt. andre m. kompetanse)

Risikovurderingen gjelder hovedaktivitet: Masteroppgave student xx. Tittel på oppgaven.

Signaturer: *Ansvarlig veileder:*   *Student:* Petter I. Bukland

ID nr	Aktivitet fra kartleggings-skjemaet	Mulig uønsket hendelse/ belastning	Vurdering av sannsyn-lighet (1-5)	Vurdering av konsekvens:				Risiko-Verdi (menn-eske)	Kommentarer/status Forslag til tiltak
				Menneske (A-E)	Ytre miljø (A-E)	Øk/ materiell (A-E)	Om-dømme (A-E)		
1	Bruk av TrollLABS makerspace								
1a-1	3D printing	Ødelegge printeren	2	A	A	C	A	2A	Opplæring i bruk av maskin
1a-2		Brannskade	3	B	A	A	A	3B	Opplæring i bruk av maskin. Unngå kontakt med utstyr under printing
1b-1	Bruk av laserkutter	Brann	2	C	A	D	C	2C	Opplæring i bruk av maskin. Ha brannslukkingsutstyr tilgjengelig.
1b-2		Øyeskade	2	D	A	A	A	2D	Opplæring i bruk av maskin
1b-3		Brannskade	2	B	A	B	A	2B	Opplæring i bruk av maskin
1c-1	Bruk av sammenføyningsmidler	Eksponering Øye	2	B	A	A	A	3B	Vernebriller

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Risikovurdering

Kode	Aktivitet / Beskrivelse	Sannsynlighet	Menneske	Ytre miljø	Øk/materiell	Omdømme	Risikoverdi	Kommentar / Tiltak
1c-2	Eksponering hud	3	A	A	A	A	3A	Sikkerhetsdatablad tilgjengelig
1c-3	Eksponering åndedrett	3	A	A	A	A	3A	Sikkerhetsdatablad tilgjengelig / Sørge for god ventilasjon
1d-1 Bruk av fres	Flyvende spon/gjenstander	3	C	A	A	B	3C	Opplæring i bruk av maskin / Alltid ha dekke foran ved arbeid
1d-2	Ødelagt maskineri	2	A	A	C	A	2A	Opplæring i bruk av maskin
1e-1 Bruk av skjæreverktøy	Liten kuttskade	4	A	A	A	A	4A	Opplæring i bruk av verktøy / Verneutstyr
1e-2	Stor kuttskade	1	D	A	A	B	1D	Opplæring i bruk av verktøy / Verneutstyr
2	Tilstedeværelse ved arbeid utført av andre — Se andres risikovurdering om sikkerhet betviles	3	C	C	C	C	3C	Hold et øye med hva som foregår rundt deg

Sannsynlighet vurderes etter følgende kriterier:

Svært liten 1	Liten 2	Middels 3	Stor 4	Svært stor 5
1 gang pr 50 år eller sjeldnere	1 gang pr 10 år eller sjeldnere	1 gang pr år eller sjeldnere	1 gang pr måned eller sjeldnere	Skjer ukentlig

Konsekvens vurderes etter følgende kriterier:

Gradering	Menneske	Ytre miljø Vann, jord og luft	Øk/materiell	Omdømme
E Svært Alvorlig	Død	Svært langvarig og ikke reversibel skade	Drifts- eller aktivitetsstans >1 år.	Troverdighet og respekt betydelig og varig svekket

NTNU		utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2604	08.03.2010
⬛	Risikomatrise	godkjent av	Erstatter	
HMS/KS		Rektor		09.02.2010

MATRISE FOR RISIKOVURDERINGER ved NTNU

KONSEKVENS		Svært liten	Liten	Middels	Stor	Svært stor
	Svært alvorlig	E1	E2	E3	E4	E5
	Alvorlig	D1	D2	D3	D4	D5
	Moderat	C1	C2	C3	C4	C5
	Liten	B1	B2	B3	B4	B5
	Svært liten	A1	A2	A3	A4	A5
				SANNSYNLIGHET		

Prinsipp over akseptkriterium. Forklaring av fargene som er brukt i risikomatrisen.

Farge	Beskrivelse
Rød	Uakseptabel risiko. Tiltak skal gjennomføres for å redusere risikoen.
Gul	Vurderingsområde. Tiltak skal vurderes.
Grønn	Akseptabel risiko. Tiltak kan vurderes ut fra andre hensyn.

NTNU HMS

	Utarbeidet av	Nummer	Dato
	HMS-avd.	HMSRV2603	22.03.2011
	Godkjent av		Erstatter
	Rektor		01.12.2006

Risikovurdering

	Menneske	Ytre miljø	Økonomi/materiell	Omdømme
D Alvorlig	Alvorlig personskade. Mulig uførhet.	Langvarig skade. Lang restitusjonstid	Driftsstans > ½ år Aktivitetsstans i opp til 1 år	Troverdighet og respekt betydelig svekket
C Moderat	Alvorlig personskade.	Mindre skade og lang restitusjonstid	Drifts- eller aktivitetsstans < 1 mnd	Troverdighet og respekt svekket
B Liten	Skade som krever medisinsk behandling	Mindre skade og kort restitusjonstid	Drifts- eller aktivitetsstans < 1uke	Negativ påvirkning på troverdighet og respekt
A Svært liten	Skade som krever førstehjelp	Ubetydelig skade og kort restitusjonstid	Drifts- eller aktivitetsstans < 1dag	Liten påvirkning på troverdighet og respekt

Risikoverdi = Sannsynlighet x Konsekvens

Beregn risikoverdi for Menneske. Enheten vurderer selv om de i tillegg vil beregne risikoverdi for Ytre miljø, Økonomi/materiell og Omdømme. I så fall beregnes disse hver for seg.

Til kolonnen "Kommentarer/status, forslag til forebyggende og korrigerende tiltak":

Tiltak kan påvirke både sannsynlighet og konsekvens. Prioriter tiltak som kan forhindre at hendelsen inntreffer, dvs. sannsynlighetsreduserende tiltak foran skjerpet beredskap, dvs. konsekvensreduserende tiltak.