INTRODUCING NOVEL LEARNING OUTCOMES AND PROCESS SELECTION MODEL FOR ADDITIVE MANUFACTURING EDUCATION IN ENGINEERING

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Abstract:
Additive manufacturing (AM) is at the verge of being recognised as one of the main manufacturing methods among the traditional ones. The largest obstacle in using AM in the companies is the lack of knowledge about the possibilities of the technology. One sub-problem caused by this is the lack of qualified machine operators in companies due to the insufficient AM education. This indicates the need for strengthen the current AM education especially in the B.Sc. and M.Sc. levels in engineering education by emphasising the importance of AM in curriculum development. This study presents novel learning outcomes based on the needs of manufacturing industry and companies in Finland. A questionnaire was conducted to work-life representatives in order to map the requirements for AM education in the mechanical engineering degree of the Lapland University of Applied Sciences in Finland. The responds were collected as competences representing different areas of AM knowledge and the learning outcomes were derived from the responds. AM education must also provide a model for selecting the most suitable AM technology in order for students to learn the technological aspects. This study also presents a process selection model which can be used in AM education. The model allows the student to compare different AM technologies from different perspectives such as material, functionality and visual appearance point-of-view.

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1. Introduction

This study presents the creation of learning outcomes for the education of additive manufacturing (AM) based on the requirements and needs of work-life in the field of manufacturing industry in Northern Finland. The study is based on a questionnaire and its results conducted to selected work-life representatives. In addition, a novel process selection model for selecting the most suitable AM technology is introduced in this study. The model is especially meant for users in the beginning of AM learning path to facilitate the selection between the most suitable AM manufacturing process. The creation of the model is based on research work from the field of AM. AM is a manufacturing method where data is extracted from 3D model in layers. This data is then used in the AM process where material is joined together layer by layer with selected technology. The term AM is officially used when discussing more advanced and expensive industrial type of 3D printers. The synonym for AM is 3D printing which is usually connected to AM equipment below the classification of these more advanced and expensive printers (SFS-EN ISO/ASTM 52900, 2017).

The success of AM is growing, especially when looked from market point-of-view. Between 2017 and 2020, the incomes of companies connected with AM have doubled which presents the growing importance of AM as one of the manufacturing technologies. In a survey conducted to 187 people working in companies in the Nordic and Baltic countries, 84% of the respondents had sufficient knowledge about AM in their own opinion and 65% saw the potential of AM in business. Despite this, it was noticed that there was a lack of information about the design principles and the price of the technology was an obstacle. The largest impacting factor to utilizing AM in as business, was the print quality (PLM Group, 2019). This shows that the basic principles seem to be in order in general level but the need for the education of AM concerning especially more detailed information about AM is needed. Therefore, this study concentrates especially in the needs and requirements addressed to the engineering education which come from the industry and companies in Finland. From educational point-of-view, AM brings practical content to the learning process by offering the possibility learn by doing. AM brings extra value to learning in many educational areas such as medical and engineering as presented in (Ullah et al., 2020; Chen et al., 2020; Wang et al., 2020 and Ford et al., 2020). The manufacturing sector is at the verge of realizing the full potential of AM in their operations. This can be seen as an increased need for the AM machine operators which automatically leads to the need for educating them e.g. during engineering studies. The demand for using the technology has increased from single manufacturing events into a complete AM process starting from CAD designing into the post-processing. 3D scanning is seen as an important part of the AM process since it offers the possibility of re-engineering parts in many areas (PLM Group, 2019; Jiang et al., 2016 and Paulic et al.,

2014). For this reason, the model for AM process selection presented in this study contains 3D scanning as a substrate for 3D model. Important note based on the experience of the authors is that even though 3D scanning is a good method to be used in the AM process, it cannot image the internal shapes of the part. This requires always proper 3D modelling.

1.1 Aim and purpose of this study

This study is focused on the creation of novel learning outcomes for learning AM based on the needs of the work-life. The main motivation for this study is the lack of proper arrangement of AM pedagogics in the literature especially when implementing AM courses in curriculum. This study is based on literature review and to the experience of the authors as educators in the area of additive manufacturing. A quantitative questionnaire was targeted to work-life representatives to point out the needs and demands for AM teaching and learning, especially from learning outcome point-of-view when implementing AM into an engineering curriculum. The arrangement of mechanical engineering degree curriculum at Lapland University of Applied Sciences in Finland works as a platform in this study from pedagogical point-of-view.

These learning outcomes can be used in engineering education in creating up-to-date AM education which meets the demands of companies and work-life representatives who are using or planning to use AM in their functions. In addition, this study presents a process selection model for learning the principles of FDM, SLA and SLS printing. This process model gives the possibility for a student to select the most suitable AM process for polymer printing from these three technologies which represent the most used AM technologies at the moment (PLM Group, 2019 and Statista, 2020). These learning outcomes and process model can be used when implementing AM into engineering education.

2. Literature review

Curriculum is a plan for arranging education consisting of information about how to define and guide learning, teaching and education. It gives the roadmap for arranging learning events in a certain degree (Karjalainen et al., 2007). One of the main factors in curriculum work is to apply different recommendations and regulations. In Europe, this is based on the National Qualifications Framework (NQF). NQF combines the degree systems of European Higher Education Institutes (HEIs´) and gives a common platform unifying the regulations of the degrees. NQF consists of eight different levels which present the education level in Europe (from basic education to doctoral degrees) (Auvinen et al., 2010; Lapland UAS, 2015 and FNAfE, 2020). Levels 6 (B.Sc.) and 7 (M.Sc.) are in focus and this study is based on the curriculum renewal process of the Lapland UAS mechanical engineering degree which took place in 2014 - 2017. This study concentrates on only to the definition of competence groups and learning outcomes concerning AM education and not to the whole curriculum process. The reason for this is that one main goal of this study is to present learning outcomes for AM education

needed in implementing it into engineering curriculum. The curriculum process has been presented in the previous stage of the Lapland UAS mechanical engineering curriculum work preceding this paper (Pikkarainen and Piili, 2020). The outcome of the process was a new curriculum which started in the Fall of 2017. The aim of the renewal process was to create a knowledge and problem-based curriculum by the real needs of work-life.

One of the main tasks of a curriculum is to set outcomes for education. These are called the learning outcomes which define what the student has to know and understand after the course. The learning outcomes are categorised into different competence groups. Competences are a set of learning outcomes which collect all the required knowhow and skills from each competence group. Competences are usually divided into general competences and subject specific competences. Therefore, it can be said that one competence group contains a set of learning outcomes derived from that competence group. This study concentrates on only to the subject specific competences since generic competences are defined in degree recommendations set by an educational agency (in Finland, the Rectors´ conference of Finnish Universities of Applied Sciences, ARENE). The subject specific competences are the ones that are implemented as substance-based topics into the courses (e.g. 3D printing which as a term is more familiar to students than AM) (Auvinen et al., 2010). The definition of the learning outcomes is important since they include the demands for learning from the work-life point of view. Drafting the learning outcomes require research work and versatile analysis of information coming from different directions such as society and work-life (Lapland UAS, 2017 and Honkala et al., 2009). The foundation of the learning outcomes dates back to 1956 when Bloom's taxonomy model defined six different categories for describing educational objectives, especially for educational purposes. The categories are knowledge, comprehension, application, analysis, synthesis and evaluation (Bloom, 1956). These categories can be seen as a path to advanced learning. Figure 1 presents the categories.
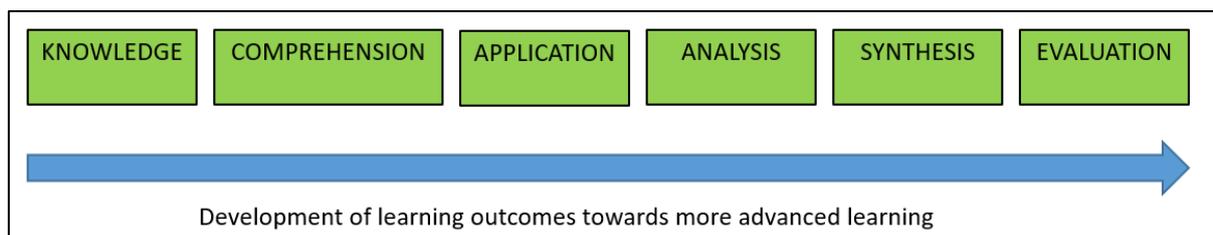

Figure 1: Development of learning outcomes according to Blooms´ taxonomy
(Applied from Bloom, 1956; Arapi et al., 2007; Meda and Swart, 2017; Stanny, 2016)

As seen in Figure 1, the following present examples, how the categories of the taxonomy can be used in defining an outcome for learning or e.g. skill to be acquired. These explanations can then be derived into actions the student must take in order to achieve a desired target in learning (Applied from Bloom, 1956; Karpen and Welch, 2016):

- *Knowledge*: to possess information and understand it (e.g. writing the laws of Newton)

- *Comprehension*: to understand the meaning and nature of information (e.g. explain the nature of gravity)
- *Application*: to have the ability to use and apply the information in different circumstances (e.g. arrange an experiment demonstrating gravity according to Newton's laws and demonstrate the main results numerically)
- *Analysis*: to be able to analyse e.g. the nature of a problem and find the factors related to possible solution (e.g. explain and analyse the effect of gravity on the part when external supports are removed)
- *Synthesis*: to combine information and e.g. ideas into solutions (e.g. produce a new learning task presenting different aspects of gravity)
- *Evaluation*: to be able to evaluate action or the nature of the solution based on to the students´ thinking or cognitive factors (e.g. select the most efficient and profitable way to perform the gravity experiment according to the preliminary test results and compare pros and cons).

In the first category *knowledge* the student acquires information for learning purposes where as in *evaluation* the student is able to evaluate and even justify his/her own learning. As these examples present the actions to be made, the creation of desirable learning outcomes requires measurable verbs to describe these functions. When the verbs are connected to the different levels of the taxonomy, the learning outcomes can be classified more specifically. Based on the experience of the main author, this way the planning e.g. of course contents, can be done more specifically when knowing what the student has to learn or to be introduced to. It shows the importance of each specific subject; what are the topics that must be emphasized in a course in theoretical form and what topics can be presented e.g. through practical methods such as laboratory work. The following presents an example of using these verbs in describing learning outcomes (Applied from Bloom, 1956; Arapi et al., 2007; Meda and Swart, 2017; Stanny, 2016):

- *Knowledge* (The student knows and can describe the laws of Newton)
- *Comprehension* (The student is able to recognize the situations where gravity takes place)
- *Application* (The student can demonstrate the nature of gravity through examples)
- *Analysis* (The student can analyse the results from gravity experiment and differentiate the different Newton laws occurring during the experiment)
- *Synthesis* (The student can combine different aspects from the laws of Newton and construct new kind of examples presenting them)
- *Evaluation* (The student is able to compare different ways to measure gravity and select most viable and appropriate method for the measurement).

Based on the experience of the main author, these verbs included in the description of the learning outcomes help the educators in planning the detailed contents of courses. They describe the desirable target for the students´ level of learning from certain subject and therefore are important factors in planning the implementation of AM into an engineering curriculum as presented in this study. When the creation of learning

outcomes is looked from a curriculum process point of view, the following stages can be noticed according to (Honkala et al., 2009):

- Analysing existing curriculum: compare the goals of the courses into the goals of the curriculum
- The description of achievable knowhow: after the completion of the course, what the student knows and can do
- The creation of the learning outcomes: learning outcomes must be written into a form which describes well the know-how of the student after the completion of a course
- Assessing the course descriptions: after the creation of the course descriptions in the curriculum, the descriptions are analysed by teachers. In this stage the quality of the course contents with respective to the curriculum are inspected.
- Assessing the learning outcomes: at this stage, the result of the learning is assessed. If the learning outcomes have been achieved, the student passes the course with accepted grade. One important part of the process is the grade criteria; the learning outcomes are assessed with respective to the criteria. This gives an insight how well the students have achieved the desired learning outcomes.

This study consists of the stage three where the learning outcomes are created. The stages one, two, four and five are part of the Lapland UAS mechanical engineering curriculum work which is not presented in this study.

3. Arrangement of AM education in Lapland UAS mechanical engineering curriculum

The curriculum of Lapland UAS includes AM in different courses and projects. The implementation of AM to the curriculum was done through taking the needs of companies and industry into account with a separate questionnaire presented in this study. It includes the experience of lecturers and research and development (R&D) personnel. Most of the AM studies have been embedded in separate courses and semester projects. Table 1 presents the listing of selected courses and projects for AM purposes.
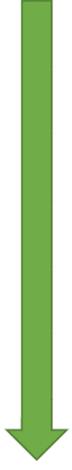
	Semester	Course name	Type of learning of AM	AM technology	ECTS
AM knowledge and experience increases	1				
	2				
	3	Project: Product development	Theoretical, design work / Theoretical	FDM / All	1 / 5
	4	Project: Prototype / 3D Design of a product	Practical / Theoretical and practical	FDM	2 / 2,5
	5	Work-life project	Theoretical and practical	FDM, SLA, SLS	5
	6	Project: Finding solution / 3D Printing and applications	Theoretical and practical / Theoretical and practical	FDM, SLA, SLS	5 / 5
	7	Project: Innovation / Future technology	Theoretical and practical / Theoretical and practical	FDM, SLA, SLS	5 / 2
	8	Bachelor thesis	Theoretical and practical	FDM, SLA, SLS	15
				MAX TOTAL	47,5

Table 1: Lapland UAS mechanical engineering AM studies in courses and projects

As presented in Table 1, the AM education is connected to courses and semester projects and it presents the maximum amount of possible ECTS points which the student can study AM topics within a course or project. One course or project is always 5 ECTS so it can be fully or partially connected to AM topics. One aim for this study was to create learning outcomes for these AM topics in order to make them to be based on the needs of the work-life and companies. The amount of credits can change according to the topics of the projects and in B.Sc. theses subject, this table presenting the estimated maximum amount of AM the student can study through the curriculum. When looking at the projects, there are always different topics for student groups, some of them linked to AM. This means that since in projects, student groups have different topics, the whole student group does not always go through the same learning path. This enables the possibility for a student to select maximum amount of AM studies, therefore each student can affect their own learning path considering the field of interest and to the professional development. The B.Sc. thesis can be linked to AM completely if the topic connects with the technology. In addition, the students can work in the AM laboratory independently making their own projects. This has been seen as major factor in the Lapland UAS in increasing the motivation of the students towards AM subjects. In addition, Table 1 presents the type of learning (theoretical education of AM or practical work on the laboratory) and the polymer printing technology used in the course or project. As seen in table 1, FDM is used in the beginning of the printing process because of its relatively easy usage and introduction into practise based on the experience from the previous AM courses in the Lapland UAS mechanical engineering degree. This is used for building the experience of the student about AM before introducing more advanced technologies such

as SLA and SLS. This relates to the inversely proportional learning of AM. The course structure supports the learning in the beginning with simpler FDM technology and it allows the student to increase the knowledge of AM towards the graduation with more advanced AM technologies and situations such as independent projects or even customer cases (Pikkarainen and Piili, 2020).

4. Methodology

The next stage was to integrate the desired learning outcomes to the content of the courses. A separate questionnaire was sent to representatives of companies and industry targeting to find out the need for arranging AM education in the Lapland UAS mechanical engineering degree. This takes the needs of work life into account when planning the AM education. The questionnaire was performed with Webpropol software via hyperlink sent to different representatives in the region of northern Finland. In addition, the link was sent via forums to companies linked with AM situated in the region of southern Finland. Business sectors of the companies were selected according to the Lapland UAS mechanical engineering degree contents. The sectors were: machine- and equipment production and installation, piping production and installation, product development, industry (the manufacturing of metal, pulp and paper) and AM. The questionnaire was arranged anonymously to protect the information of the companies. Total of 56 responses was received. It can be stated that the questionnaire was arranged during spring 2020 when the COVID-19 pandemic was at its first wave in northern Europe at this clearly affected the number of responses when companies and industry were facing new kind of challenge in their operations.

The questionnaire collected some basic information from the responders (n=56) in order to identify the basic functions of the companies and to get a view about the responders. The term 3D printing was used in the questionnaire because of its popularity as a general term. The responders were allowed to select more alternatives per answer, hence the greater number of responds compared to the number of responders. The questionnaire contained questions whether the responder use or produce 3D printing services of not. Despite the answer the responder was allowed to continue in the questionnaire in order to collect information and opinions about 3D printing in general. This information gives an insight whether the company uses 3D printing primarily or secondarily in their functions. This refers to the employment options for the student specialized in 3D printing. The analysis of the basic information shows that the division between the usage, production or need for 3D printing is quite even. Basic 3D printing operations such as printing work, post-processing and design work are regarded as the most important operations in the manufacturing process. Companies informed that the most needed information about 3D printing were design principles, knowledge about the technologies and materials, possibilities provided by 3D printing for the company and last, the price factors behind 3D printing. Appendix 1 presents the details from the basic information from the responders.

The second part of the questionnaire consisted of 16 different questions where different areas concerning 3D printing and especially the needed know-how were mapped. The nature of the questions was selected according to the topics connected generally to 3D printing education. The aim of this was to receive an insight about the importance of the different factors. From these, the required learning objectives and competences will be analysed and written for the curriculum purposes. Figure 2 presents the arrangements of the questionnaire scale.

Figure 2: Questionnaire scale

As presented in Figure 2, a scale from zero to ten was used. The value zero presented the meaning "not important at all" and the value ten presented the meaning "Highly important. In addition, an option "I cannot say" (CNS) was included.

5. Results

The results were collected into a table format including the number of responses and their percentages. The scale from 1 - 10 was divided into three categories: from 0 – 6, 7 – 8 and from 9 – 10, the mean value of the responses was included. The number of "I cannot say" (CNS) responses was left out from the calculation of the mean value. Appendix 2 presents the numerical results from the questionnaire.

The answers were focused on to the scales from 7 – 8 and 9 – 10. This gives larger variation to the results than the normal 1 – 5 scale. For the analysis of the results, topics with mean value over 8.0 are considered important in this study. The lower mean value (e.g. 6 – 7) means that the topic is not so important or familiar to the companies. Since the topics of the questionnaire were selected according to the current 3D printing topics, these lower value responses can be seen as something that could be introduced to the companies through graduated engineers as they are employed to the companies.

The following conclusions can be drawn from the responses:

- The basic information of 3D printing e.g. different printing technologies, additive manufacturing (AM) process and basic principles are considered very important. Besides the mean value of 8.2, the percentage of 9 – 10 answer is 52.83%. This shows that the basic education (including theory and practise) is very important since from education point-of-view, this forms the foundation of 3D printing knowledge.
- 3D printing with metal is more important; this is because of the fact that mechanical engineering in northern Finland focuses more on metal industry (through the production of stainless steel and the companies connected with metal

manufacturing). Even though the situation is this, based on the experience of the main author, working with polymer materials in the beginning of the 3D printing studies presents easier start to the studies because of to the nature of the material. Printing with polymers present e.g. shorter build time, the level on required expertise is lower and post processing is simpler.

- Design principles (e.g. DfAM = Design for Additive Manufacturing) are considered very important.
- The special features of modern 3D modelling such as the structural optimization according to strength and reducing the number of parts (part consolidation) in assembly are important. Based on the experience of the main authors, these are topics that fit well into 3D printing because of the fact that they are a part of engineering design principles. By connecting the engineering design principles with 3D modelling, 3D printing brings an excellent way to visualize the principles in real-life (learning by doing).
- The usage of 3D printing in the functions of the company or industry is considered important. This included noticing the possibilities of using 3D printing e.g. in part manufacturing and also defining the viability of 3D printing in the product manufacturing processes.

When looked at the responses with a lower number of importance, the following conclusion can be drawn:

- The 3D printing of polymers and its possibilities is seen less important than the one of the metals. One reason for this is that in the region of northern Finland, metal industry plays a major role in the manufacturing industries.
- Companies are not willing to arrange joint projects with the engineering education. Possible reasons for this are the lack of resources for the cooperation (time and personnel) and the lack of connections to the University. In addition, the COVID-19 situation during the moment of the questionnaire can affect the current motivation to perform joint projects. Functional cooperation requires a personal connection to the company so that both sides commit to the project (Steinmo and Rasmussen, 2018).
- Recycling of 3D printed parts is still yet quite unknown, especially with polymer materials. This requires active research from the University so that the graduated engineers would have knowhow from this to be taken with them to the companies.
- Circular economy is still rather new topic in Finland. 3D printing offers possibilities to this, especially through part re-manufacturing and like with recycling, this is a topic that need to be supported in engineering education.

In addition, the questionnaire included a section for free form answer considering the following question: "What kind of expertise a future engineer needs regarding the usage of 3D printing in companies and industry?" From 56 responders, 21 gave an answer. The following presents the collected answers:

- The importance of 3D printing as a part of traditional mechanical engineering and the different applications of it. This includes the basic understanding of the possibilities and limitations of the technology.
- The design work for 3D printing should take into consideration the real operating conditions of the parts and products. This requires the understanding how machines work, for instance.
- The designer should be able to distinguish the meaning of 3D printing in a prototype, small series and mass production.
- The evaluation of the viability of 3D printing in the long run is important because of the fact that 3D printing will be more and more competitive in the future. This was included in the questionnaire which emphasizes the importance of this topic.
- Topology optimization and the recycling issues and circular economy will be greater factors in the future. This was included in the questionnaire which emphasizes the importance of this topic.
- The DfAM and topology optimization requires deeper understanding about material properties. The Finite Element Method (FEM) and surface modelling are important factors needed in the optimization. This was included in the questionnaire which emphasizes the importance of this topic.
- 3D printing of spare parts from even more sustainable material together with form optimization continues the life cycle of the product and saves costs.
- The possibilities of utilizing 3D printing in the region of Northern Finland are limited.
- Finding real and profitable 3D printing targets and needs is important.
- The basic know-how of 3D printing is something that needs to be in order (with polymers and metals) when an engineer graduate. This includes the basic understanding how the AM process (e.g. printing and post processing) affects to the material properties.
- The designer has to have basic understanding from 3D scanning.

These comments present important information about the tacit demands from work-life which should manifest in modern engineering education. The comments will be used together with the numerical responses in creating valuable information to the Lapland UAS mechanical engineering curriculum.

6. Analysis

The responses from the questionnaire form the frame for the creation of the required learning outcomes and competences in this study. These will be used in the Lapland UAS mechanical engineering curriculum and they can be used in other universities when planning AM courses. The target is to concentrate on AM of polymers because of Lapland UAS AM environment do not contain metal AM. Therefore, metal AM is viewed only from theoretical aspects. Table 2, 3 and 4 present the collected descriptions for the competence groups which have been derived from the questionnaire and the learning

outcomes. In Table 4, the free word answers have been combined into more reasonable competence entities. The learning outcomes have been divided into six different categories based on the Blooms´ taxonomy. These categories help to place the learning outcomes in right courses since they present the level of learning at different levels (Applied from Bloom, 1956; Arapi et al., 2007; Meda and Swart, 2017; Stanny, 2016). In addition, the nature of the Blooms´ taxonomy enables the planning of the AM courses order in a way which grows the students´ knowledge about AM evenly during the studies.

QUESTION TOPIC = COMPETENCE Average > 8,0	CATEGORY	LEARNING OUTCOME (The student...)
1. Basics of 3D printing - AM technologies - AM principles - AM process	KNOWLEDGE KNOWLEDGE COMPREHENSION EVALUATION	Can identify different AM technologies Can define the AM principles Is able to compare AM processes and distinguish them from each other Can select the most suitable AM process for application
2. 3D printing of metals - technology, possibilities	KNOWLEDGE COMPREHENSION	Can identify the possibilities of metal 3DP Understands the basics of metal 3DP Can differentiate metal 3DP from polymer 3DP
3. Design principles (DfAM)	COMPREHENSION APPLICATION	Understands the meaning of DfAM in design work Can apply the DfAM principles in design work
4. Optimization of 3D models (e.g. topology optimization, part consolidation)	COMPREHENSION APPLICATION ANALYSIS SYNTHESIS	Understands the meaning of structural optimization in AM Can perform str.opt. based on engineering design principles Can distinguish the targets for optimization Can design optimized structures for AM
5. AM in companies - utilization in company functions	EVALUATION	Is able to perceive the possibilities of utilizing AM in company functions
6. Viability of 3D printing Definition in the product manufacturing process	KNOWLEDGE COMPREHENSION SYNTHESIS EVALUATION	Can define the viability in 3D printing Understands the cost structure of AM and its relationship with viability in product manufacturing Can develop profitable parts through AM Can compare the different AM technologies cost-wise

Table 2: Competences and learning outcomes derived from answers with the average of >8,0

QUESTION TOPIC = COMPETENCE Average < 8,0	CATEGORY	LEARNING OUTCOME (The student...)
7. 3D printing of polymers - technologies - possibilities	KNOWLEDGE COMPREHENSION	Can identify the possibilities of polymer 3DP Understands the basics of polymer 3DP Can differentiate polymer 3DP from metal 3DP
8. Practical exercises - polymer / metal 3DP	APPLICATION ANALYSIS	Is able to use selected AM technology independently Can choose the most suitable AM technology for printing
9. Project learning - common projects between education and companies	SYNTHESIS EVALUATION	Can adapt the AM principles into real-life projects Is able to compare the produced solutions and select the best alternative
10. Recycling - 3D printed parts and materials	KNOWLEDGE COMPREHENSION	Recognizes different polymer materials and usage purposes for 3D printing Understands the principle of recycling polymer 3D printed objects and filament fabrication
11. Re-manufacturing (circular economy)	COMPREHENSION ANALYSIS SYNTHESIS	Understands the meaning of re-manufacturing of products Can point out the possibility for re-manufacturing Can design products according to the re-manufacturing principles

Table 3: Competences and learning outcomes derived from answers with the average of < 8,0

QUESTION TOPIC = Free word	CATEGORY	LEARNING OUTCOME (The student...)
12. 3D printing in engineering - as a part of traditional mechanical engineering - possibilities and limitations - distinguish different applications - reflecting into real situations (e.g into function principles of machines)	COMPREHENSION COMPREHENSION APPLICATION ANALYSIS ANALYSIS SYNTHESIS SYNTHESIS	Can illustrate mechanical functions through 3DP Understands the possibilities and limitations of 3DP Can identify the possibilities and limitations of 3DP in mechanical engineering Can distinguish 3DP as a manufacturing method from the traditional ones Can distinguish different 3DP applications (prototyping, small series, mass production) Can combine 3DP into traditional mechanical engineering topics Can adapt 3DP into real situations (e.g. mechanical functions)
13. 3D printing and life-cycle - spare parts and product life-cycle	COMPREHENSION APPLICATION	Understands the role of 3DP in part life-cycle Can identify the targets for spare part production through 3DP
14. 3D scanning knowhow - basic understanding and applications	COMPREHENSION APPLICATION SYNTHESIS	Understands the principle and possibilities of 3D scanning in 3DP Can use 3D scanning in the production of data for 3DP Can compile and covert 3D scan data into a format for 3DP

Table 4: Competences and learning outcomes derived from free word answers

As seen in Tables 2, 3 and 4, the topics can be applied into many of the presented categories. This enables the usage of the learning outcomes in a more versatile way in courses. The goal is to build the AM knowledge along the semesters so that the more advanced learning happens in the later courses. The next step is the integration of the derived competences to the curriculum. This happens via competence matrix analysis where presented competences are linked to courses. The linking should be done in a way which supports the students´ development into an expert during the studies. This creates a list of competences which the student will possess during the studies and after graduation (Honkala et al., 2009). It creates the desired learning outcomes per course and helps to design proper course structure for AM education. When planning the detailed contents of courses, necessary learning outcomes can be selected from the competence groups. The term 3D printing is used also here. Table 5 presents the competence matrix.

Semester		1. Basics of 3D printing	2. 3D printing of metals (theory in Lapland UAS)	3. Design principles (DfAM)	4. Optimization of 3D models	5. AM in companies and industry	6. Viability of 3D printing	7. 3D printing of polymers	8. Practical exercises	9. Project learning	10. Recycling	11. Re-manufacturing	12. 3D printing in engineering	13. 3D printing and life-cycle	14. 3D scanning know-how
3	Project: Product Development	x		x			x						x		
3 or 4	3D printing (book exam)	x	x	x			x	x					x	x	
4	Project: Prototype	x		x			x	x					x		
4	3D Design of a product	x		x			x	x				x	x	x	
5	Work-life project			x	x	x	x	x		x					
6	Project: Finding solution	x		x	x	x	x	x	x	x		x	x		x
6	3D Printing and applications	x	x	x	x	x	x	x	x	x	x	x	x	x	x
7	Project: Innovation			x	x	x			x	x	x	x	x	x	
7	Future technology			x	x	x		x	x	x	x	x	x	x	
8	Bachelor thesis	x	x	x	x	x	x	x	x	x	x	x	x	x	

Table 5: Lapland UAS mechanical engineering AM studies in courses and projects

As seen in Table 5, the competences have been linked to courses with the matrix table. On the vertical section, are the possible studies linked into 3D printing and in the horizontal section, the competence groups. This part of the curriculum work shows, what competences are achieved in certain courses and how the competences develop during the 4-year studies of the Lapland UAS mechanical engineering degree. When the detailed contents and description of a course are planned, the competence matrix shows what kind of targets for AM learning there should be. As an example, here are the learning outcomes from the course "3D design of a product" derived from the matrix: *In the course, the student identifies different AM technologies and can define the AM principles. The student is able to compare different AM processes and distinguish them from each other and select the most suitable one for manufacturing considering polymer printing with practical exercises. The student understands the design principles of AM (DfAM) and can apply them in design work. The student understands the life-cycle and recycling of polymer products and is able to take them into consideration in the design work. The student can illustrate mechanical functions through 3D printing and understands the possibilities and limitations of the technology*".

Based on the experience of the main author, when the learning outcomes are described within the course, the different competence parts can be connected together in the description in order to make the learning outcome description more fluent. When the matrix shows a cross marked to a specific competence area, the required learning outcomes are selected to the course according to the level of the course. This means that all of the learning outcomes within the competence area are not always selected within one course. This description of the planned learning outcomes shows the result from the learning process when the student has completed the course with accepted grade. The detailed description of the learning outcomes within a course helps to recognize the acquired skills within the engineering degree when e.g. applying for a job.

7. Arranging AM education

The Lapland UAS 3D printing laboratory function leans to the usage of three different technologies, FDM, SLA and SLS. When the situation in the Nordic and Baltic countries is looked, these technologies present the most used AM technologies whereas plastics are the most used material (PLM Group, 2019). From educational point-of-view, a presentation of different AM applications is an important starting point for learning. According to PLM Group (2019), the most used application is using AM for prototyping (82%). The other applications (concept verification 65%, production tools 64%, end-use parts 41% and spare parts 32%) show the other areas where AM is used. Properties from each technology present possibilities for the student to learn and apply AM. The traditional AM process is based on the practical steps to be taken in order to print (3D modelling – STL conversion – slicing – machine setup – printing – removal – post processing) (Gibson et al., 2021). It can be stated that this basic AM process does not take the other views such as learning or selecting the most suitable AM technology into account. Therefore, more detailed model for the actual AM process selection is needed in

order to specify the different learning aspects of the technologies and select the most suitable AM technology. According to 3D Hubs (2020), one way that fits well with engineering education, is to start the selection by dividing the AM applications into material, functionality and visual appearance as seen in Figures 3,4 and 5. All the materials and technologies have been limited into polymers and to the three technologies (FDM, SLA and SLS) mentioned in this study.
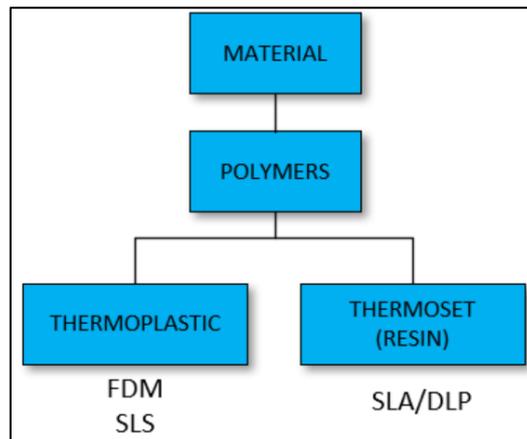

Figure 3: AM technology selection according to material
(Adopted from 3D Hubs, 2020)
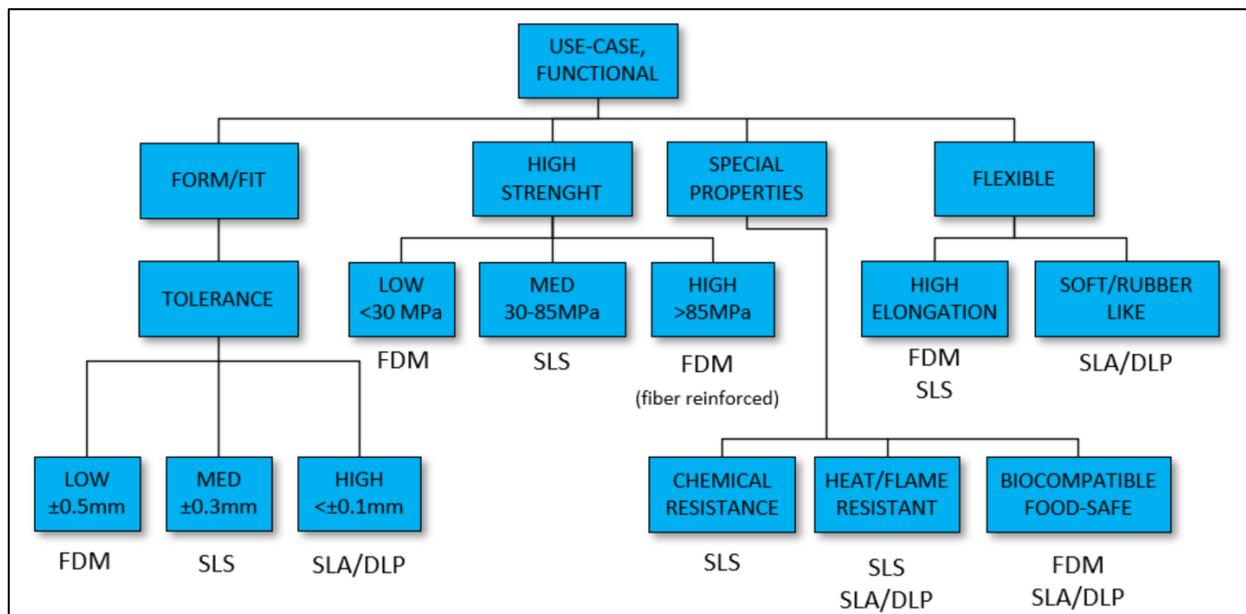
Figure 4: AM technology selection according to material
(Adopted from 3D Hubs, 2020)
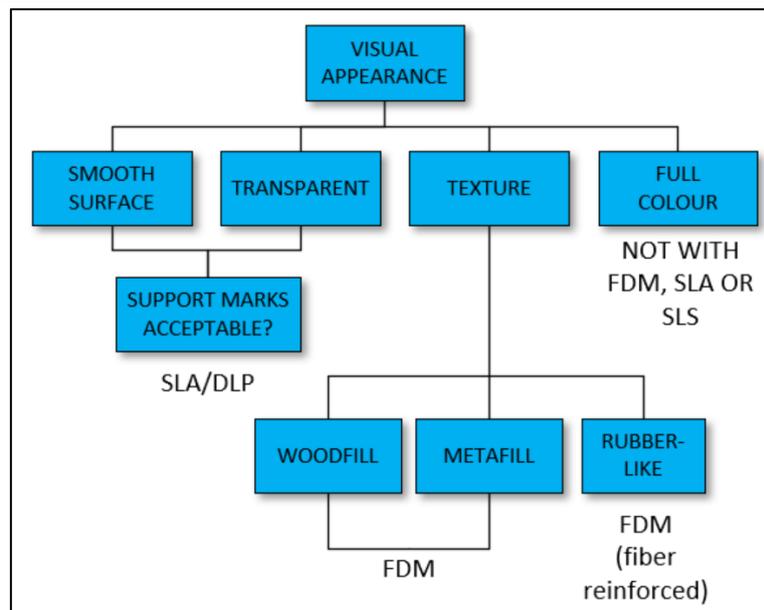
Figure 5: AM technology selection according to material
(Adopted from 3D Hubs, 2020)

Figures 3, 4 and 5 present three different ways to select the most suitable polymer printing technology. The selection requires the knowledge of the used material and the definition of the desired attributes. The specifications and demands of the design and build (e.g. accuracy) must be chosen and known (3D Hubs, 2020). Digital Light Processing (DLP) refers to one type of AM technology based also to photopolymerization such as SLA. DLP uses mask projection system to cure an entire layer at once where SLA uses laser and scanning galvanometer to cure layer point-wise (Gibson et al., 2021).

This division is used as a starting point in this study when more detailed selection of the correct printing process from a learning point of view is introduced. Figure 6 presents the detailed model for AM process selection.

As seen in Figure 6, the model presents a way to connect a traditional engineering design process with the basic idea of product development into AM process selection. The user designs the desired part with traditional design process principles (DfAM = Design for Additive Manufacturing principles included), which is usually based on a need. As a part of a product manufacturing process, 3D scanning can be used in this stage through reverse engineering. The physical 3D model is then analysed and possibly optimized through topology optimization and part consolidation. This stage enables the optimization of the structure and the preliminary definition of material properties. This already lays the ground for the actual AM process selection for manufacturing.
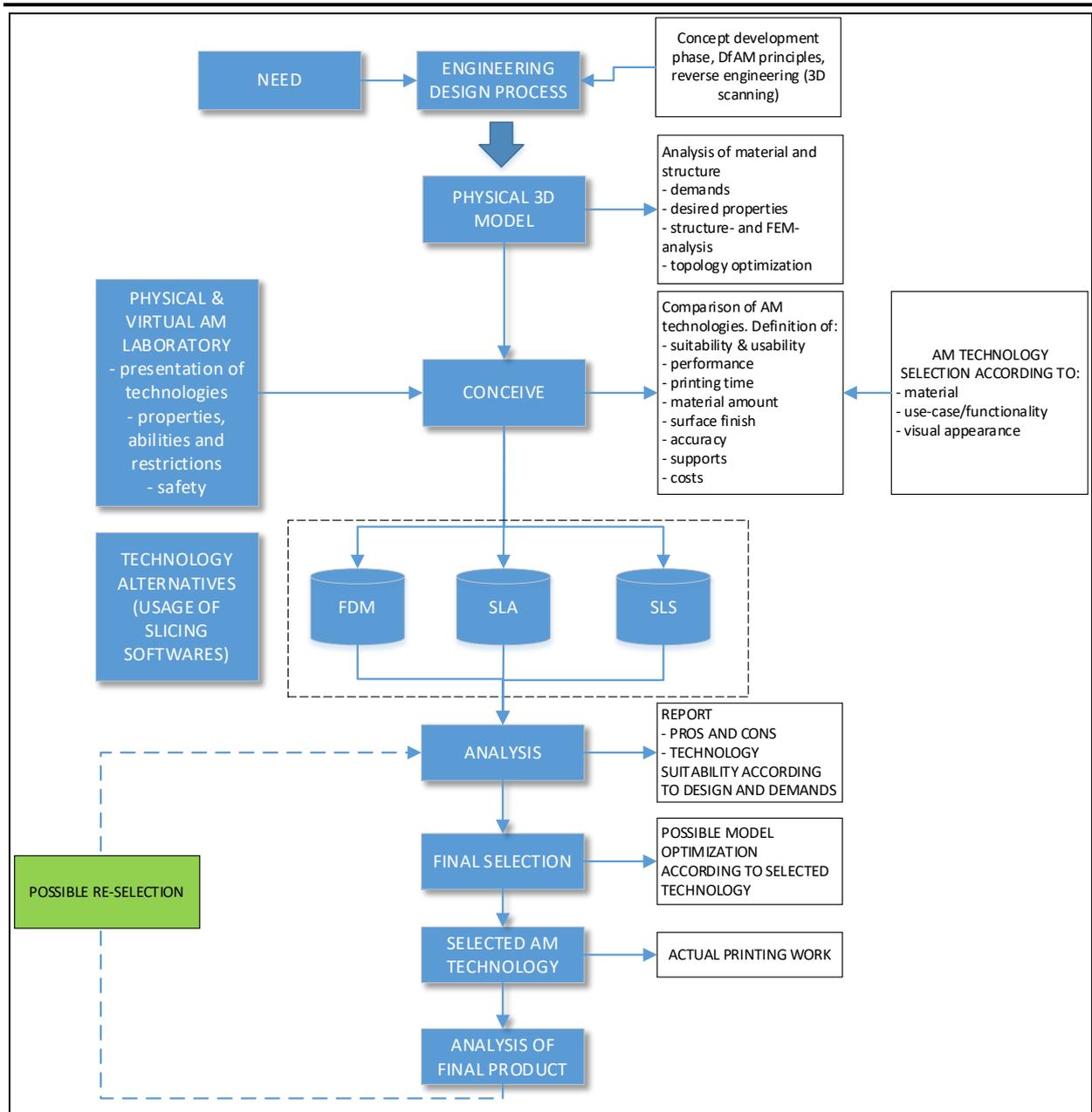
Figure 6: AM process selection model

In the conceive stage, the user is introduced to the laboratory environment first via virtual information tour. Before this, the student has already received necessary theoretical information about AM according to the curriculum. The virtual laboratory tour includes a 3D virtual model of the laboratory where the user can move around and introduce to embedded information about the printers. During the writing of this study, the virtualisation is at the planning stage and will be implemented later. After this, the practical introduction to the printers will be given in the laboratory (usage, safety, material loading etc.). These two stages give the user the required information about the laboratory in order to function there for learning purposes. At this stage, the possible technologies are reflected with the model according to different factors. This stage gives the user information for making the decision about the technology to be selected

according to different criteria such as performance, accuracy. The basic AM process selection according to material, use-case/functionality or visual appearance is used at this stage. This stage includes studying the theoretical background about the technologies performed either before or during a certain course.

In the next stage, the user is introduced to the available technologies and comparison of the 3D printer connected slicing software. All the pros and cons of the technologies in relation to the 3D model are listed and the product demands are reflected with the technologies. This stage gives the user the final information for making the decision of the most suitable technology. When selecting the right technology, the user can still optimise the model if the technology has some special perspectives or demands in the manufacturing process. The manufactured part is analysed and if the result was not successful, the user return to the selection phase through iteration. This enables the quality of the manufactured part. The model can be used for learning purposes through selecting the most suitable AM process. The stages, where user has to acquire information or analyse a certain stage, enable the learning of different aspects of AM. Model is meant to be used in the beginning of the learning process and by using the most suitable AM technology, experience and knowledge increases. This creates a behaviour model for the user and when the process is familiar, the user can make the process selection with less phases.

8. Conclusion

The modern manufacturing industry is based mostly to traditional methods and additive manufacturing is on the verge of becoming recognized one of the reasonable alternatives for product manufacturing. In order to make this happen, the information about the possibilities of AM must be increased in the industry and companies. In order to increase the AM processes in the manufacturing industry, qualified machine operators are needed in addition to the AM knowledge. This sets requirements to engineering education and through proper arrangement of the AM education, it can produce necessary experts the work-life needs. Therefore, the development of curriculum and especially the detailed contents of AM courses are in focus. This requires the proper description of the required learning outcomes since it has to meet the demands set by the manufacturing industry. This can be divided into two different scenarios. In the first, the manufacturing industry is aware of the possibilities of AM and is using it in their functions. The industry and companies can direct the demands for AM skills and know-how to the engineering education. This way the engineering education can educate the professionals with the right AM knowhow. The other scenario is where the industry and companies are not using AM in their operations and are even lack information from AM. In this case, the function of the engineering education is to increase the awareness about the possibilities of AM through graduated engineers when they are employed. In this study, the questionnaire directed to the industry and companies in Finland presents that the situation is a hybrid of these. In either case, the engineering education must contain the

proper skills for using AM as one alternative for manufacturing. Results from the conducted questionnaire can be formed as competence groups and within these, proper learning outcomes can be created which gives the pedagogical background to the required know-how from curriculum point-of-view. The competence matrix connects the competences with courses and this enables educators to plan the learning path along the whole degree so that the student can develop to become an AM expert.

The practical arrangement of AM education needs to be considered together with the pedagogical aspects. It is important for an engineering student to be able to select the most suitable AM technology for manufacturing. AM contains many factors that affect to the selection of the process and this study presents a model, how the selection between the most used AM technologies, FDM, SLA, SLS can be done. This model can be used with other technologies even if the technology (such as AM of metals) contains more specific aspects and demands for manufacturing. This model gives a substrate for using these more complex AM technologies as it presents a clear path for connecting AM technology into engineering design and to the features of the selected technology. The complete AM selection models, as presented in (3D Hubs, 2020), contain the AM technologies of metals. The versions used in this study have been adopted only to contain the selected three polymer AM technologies. The learning outcomes and AM process selection model will be used in future study where a group of Lapland UAS mechanical engineering students will study the basics of FDM, SLA and SLS technologies in a course. The student perspective will present the learning experiences between the technologies and present the learning threshold of each technology which will help in planning the actual usage of AM technologies in courses.

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Appendix 1: Responses from Basic Information

	n	Percentage (out of n=56)
1. The number of employees in the company?		
Less than 10	19	33.93%
10 - 50	12	21.43%
50 - 250	8	14.28%
Over 250	17	30.36%
2. Does your company use 3D printing services?		
Yes	31	55.36%
No	25	44.64%
3. 3D printing services used by the company		
Optimization of 3D models	12	38.71%
Design of 3D printed parts	15	48.39%
3D printing work	28	90.32%
Post processing	17	54.84%
3D scanning	15	48.39%
Other (specify)	1	3.23%
Other:		
The simulation of the 3D printing process		
4. Does your company produce 3D printing services?		
Yes	27	48.21%
No	29	51.79%
5. The 3D printing services produced by the company		
Design work	21	77.78%
3D printing work	20	74.07%
3D printer training	11	40.74%
3D printer sales	5	18.52%
3D scanning	13	48.15%
Other (specify)	7	25.93%
Other:		
The simulation of the 3D printing process		
Product development and optimization		
Modeling		
Fabrication of metal powder for 3D printing		
Materials for 3D printing		
Technical calculation and structural optimization		
6. Does your company need information about 3D printing		
and its principles in the functions of the company?		
Yes	31	55.36%
No	25	44.64%
7. Information needed about 3D printing		
Design principles in 3D printing	24	77.42%
3D printing technologies and materials	25	80.65%
Possibilities provided by 3D printing for the company	24	77.42%
Price factors in 3D printing	22	70.97%
Other (specify)	4	12.9%
Other:		
General information about new 3D printing technolgies and materials		
Details in 3D printing		
The material models of printing materials for technical calculation		
Continuous learning in each area		

Appendix 2: Numerical Results from Responses

Scale	0 - 6	7 - 8	9 - 10	CNS	Mean value
1. How important are the following topics in engineering education: Basics of 3D printing (technologies, principles, process)?	7	18	28	3	8.2
	13.21%	33.96%	52.83%		
2. The 3D printing of polymers and its possibilities.	9	24	21	2	7.7
	16.67%	44.44%	38.89%		
3. The 3D printing of metals and its possibilities.	5	20	29	2	8.4
	9.26%	37.04%	53.7%		
4. Knowledge of polymer materials in 3D printing	15	22	17	2	7.2
	27.78%	40.74%	31.48%		
5. Knowledge of metal materials in 3D printing	11	22	21	2	7.9
	20.37%	40.74%	38.89%		
6. Knowledge of composite materials in 3D printing	15	19	19	3	7.5
	28.3%	35.85%	35.85%		
7. Practical exercises in 3D printing of polymers	16	23	15	2	7.1
	29.63%	42.59%	27.78%		
8. Practical exercises in 3D printing of metals	17	20	17	2	7.4
	31.48%	37.04%	31.48%		
9. Design principles in 3D printing	4	15	34	3	8.8
	7.55%	28.3%	64.15%		
10. The optimization of 3D models (parts consolidation, topology optimization etc.)	9	12	32	3	8.3
	16.98%	22.64%	60.38%		
11. Possibilites to utilize 3D printing in the company functions	7	17	30	2	8.4
	12.96%	31.48%	55.56%		
12. Possibilites to utilize 3D printing in the industry	4	15	34	3	8.6
	7.55%	28.3%	64.15%		
13. The definition of viability of 3D printing in the product manufacturing process	6	20	27	3	8.4
	11.32%	37.74%	50.94%		
14. The common projects of engineering education and companies	13	26	14	3	7.3
	24.53%	49.06%	26.41%		
15. The recycling of 3D printed parts and materials	24	19	11	2	6.4
	44.44%	35.19%	20.37%		
16. Re-manufacturing of products through 3D printing (circular economy)	18	15	19	4	6.8
	34.61%	28.85%	36.54%		