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The meaning of knowledge transfer in educating engineers for modern manufacturing technologies

H Piili[1], **A Huusko**[1], **A Kurvinen**[2], **A Pikkarainen**[3]

[1] Department of Mechanical Engineering, Faculty of Technology, Research group of Digital Manufacturing and Surface Engineering (DMS), University of Turku, Turku, 20520, Finland
[2] Department of Business, International Business, LAB University of Applied Sciences, Lappeenranta, 53850 Lappeenranta, Finland
[3] Department of Mechanical engineering, New Industry expertise group, Lapland University of Applied Sciences, Kemi 94600, Finland

ari.pikkarainen@lapinamk.fi

Abstract. The development of modern manufacturing technologies such as additive manufacturing and other laser-based manufacturing technologies have increased their usage, especially in engineering education. Education must correspond to different applications of these technologies to ensure the quality of their usage in the manufacturing industry. Laser-based technologies have an impact on society through companies and industry in the manufacturing sector as they are employing graduated students, who are more aware of the possibilities of the technologies. Traditional manufacturing industries are facing the era of digital transformation. There are vast differences between industries and different industry players as well as their ability to keep up with the transformation process. The pace of the process can depend on many different items that are related to the company organization and leadership, technology base and to the abilities to modify these. The pace can also depend on the processes of cooperation and development between other ecosystem players e.g., supply chain partners or development drivers such as customer industries. This study concentrates on one of the key issues, namely learning and adoption of new skills to tackle the change. Universities have a major role in the knowledge transfer from education to working life. To develop this, there is a need to identify the factors in university training or pedagogical choices that can speed up the process of transformation. The aim of this research is to identify the factors for knowledge transfer through arranging efficient education for laser-based manufacturing technologies, especially in engineering education. It was concluded that by educating engineers with sufficient knowledge about the technologies, the manufacturing industry can utilize the knowledge and implement laser-based technologies better in their operations.

1. Introduction

Additive manufacturing (AM), known also as 3D printing, is a rapidly developing and expanding manufacturing process, in which material is added layer by layer. Other conventional manufacturing technologies the contrary rely on e.g., subtract or join materials. This approach of AM makes it a unique technology to create totally new applications by utilizing design freedom, as e.g., in [1] and [2]. Recent studies have also indicated that AM is gaining acceptance in novel material engineering and industrial engineering. Novel industrial applications are developed in the electronics, automobile, aerospace, and petrochemical industries, as discussed in [3] and [4]. For instance, AM has been playing a crucial role

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in recent years in the aerospace industry. Boeing is developing a communications satellite with over a 1000 additively manufactured parts made of titanium and aluminium and a high-performance polymer, as in [5]. Perseverance rover of NASA was the first one to carry additively manufactured ceramic parts to Mars. This has increased the reliability of the rover according to NASA, as in [6] and [7]

Additive manufacturing includes wide variety of different manufacturing techniques, each with device-specific variations. In addition, each equipment manufacturer has named its own processes differently. [8] Different technologies are suitable for different products, and additive manufacturing is characterized not only by a wide range of technologies but also by applications. New techniques and variations on existing technologies are also being developed, which further increases the wide range of terminology in the field, as e.g., in [9]. New technologies and upgrades enable, for example, the use of new materials, higher manufacturing speeds and, as construction chambers grow, the manufacture of larger pieces. One of the hot areas of research is the so-called additive manufacturing of multi-material, which is studied in different parts of the world. For this technology, the application can be, for example, process industry products where the outer casing of the tank is a pressure vessel made of steel and the inside is corrosion resistant, e.g., stainless duplex steel. More discussion in [10] and [11]. Software development also opens new opportunities for designing better and optimised structures, which is one of the cornerstones of the utilisation of AM. On the software side, development is fast and significant. Several very successful projects have already been carried out in Finland, where the functions of hydraulic components have been optimised with computational fluid dynamics (CFD) software and manufactured with additive manufacturing. Often the weight of these parts drops significantly and e.g. pressure drop in flow components drop to a fraction compared to a traditional design. In the future, Finland can also see strong development in these areas, as in [13].

The rapidly developing field of additive manufacturing also increases the need for continuous training to keep up with the development of the field. Although additive manufacturing can offer benefits in optimizing and manufacturing many parts, the growth seen now will not increase the share of additive manufacturing in the manufacturing process market very quickly unless the issue is highlighted and promoted in all possible situations. Technological development in different areas of AM is happening rapidly now and will fuel new applications and growth opportunities [14] Education is key to increasing the use of additive manufacturing. Training is needed at all levels of the organization to ensure management support for product development print ideas. Training experts, such as to the area of AM, is the key function where engineering graduates and work-life professionals are trained through engineering programs and short-term courses. This is concluded e.g., in [15] and [16]. These allow them to apply the technologies in companies and support and industrialize the technologies. This enables the development of the technology and though using it in companies, support the usage of the full potential in company operations [17].

Knowledge embedded in the interactions of people, tools, and tasks forms a basis for competitive advantage in firms. [18] Knowledge transfer is needed in the shop floor level in production work, but it is also reflected in product development, and finally company management understanding in the topic and meaning of new knowledge to the business. Universities have a role in knowledge transfer of new technologies to the manufacturing industry. As technological change is very rapid, also more thought should be given to the way technology transfer can be speeded up. Degree education and training offered by universities are both ways of knowledge transfer in traditional perspective. Traditional ways and university pedagogy need to be adjusted to meet the needs of the industry and the pace of change in industry. These facts are revealed by figure 1 which shows number of publications according to Scopus with different keywords used.

It can be concluded from figure 1 that number of publications generally in field of additive manufacturing and 3D printing has started to increase strongly in 2016. The same trend can be noted also with number of publications in field of engineering and simulation. Figure 1 reveals also that number of publications in field of learning and training in significantly less than corresponding number in additive manufacturing. Figure 1 indicates also that number of publications in field of learning has been in 2022 only 12% from corresponding number of additive manufacturing, and number of publications in training has been 6% and number of publications in knowledge transfer 0.3%. It can be concluded from figure 1 that this study has huge importance, and there are only very few publications available in this field.

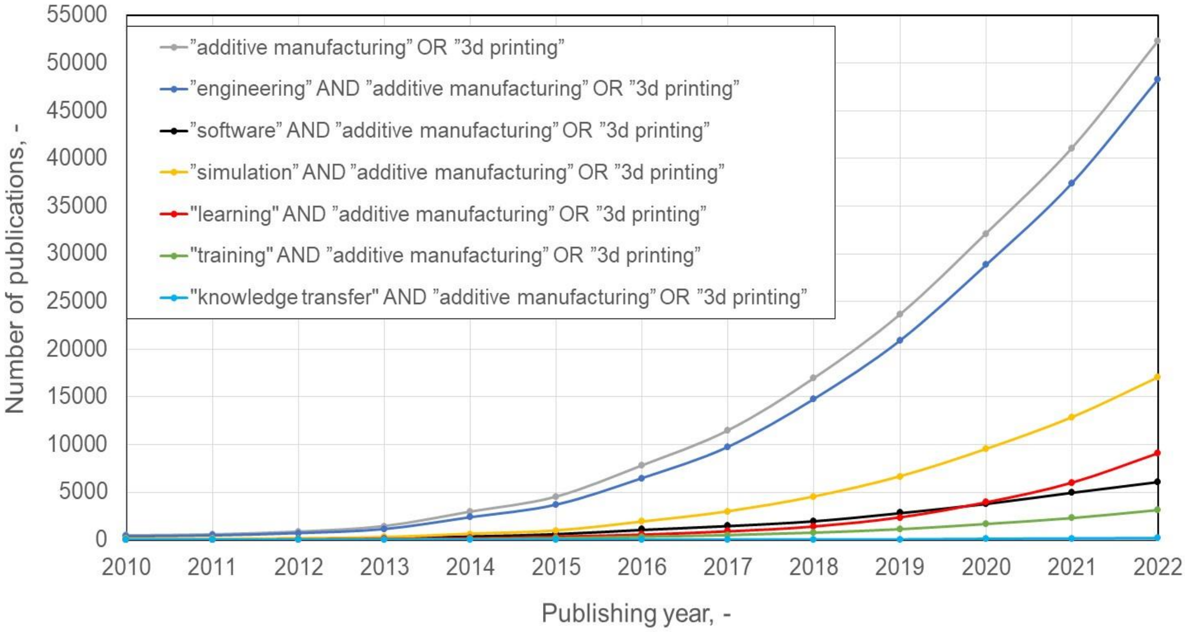

Figure 1. Number of publications according to Scopus when different keywords were used.

This study examines the adoption of additive manufacturing knowledge as a modern manufacturing technology, emphasizing the need to stay updated in the evolving field. In this study, two different cases are discussed, knowledge transfer through a Master level degree programme and AM training offered directly to companies. This study emphasizes the importance of a trained workforce for companies adopting these technologies. The study aims to propose solutions for technology-based knowledge transfer from education to companies, enabling increased technological proficiency and productivity. The scarcity of articles in this field, as identified through a Scopus survey, highlights the significance of this research. Industrial importance lies in manufacturing companies adopting and testing new ideas for business development, while change processes depend on various factors such as organizational structure, leadership, and technology base.

2. Literature review

2.1. Laser-based manufacturing technologies

Additive manufacturing includes large number of applications and subcategories. It is a process that builds up a physical object layer-by-layer, using a digital model as a guide. Additive manufacturing is divided into seven subcategories, including material extrusion (ME), vat photopolymerization (VP), powder bed fusion (PBF), directed energy deposition (DED), binder jetting (BJ), material jetting (MJ), and sheet lamination (SL) [19] Each of these subcategories has its own set of advantages and disadvantages, and they are used in different applications. Under these seven subcategories, there are dozens of different technologies with different material options, different possibility to fabricate various sizes of product, various device types starting from consumer devices to industrial scale large AM systems and different costs of devices. These technologies are constantly evolving, and new ones are being developed all the time, as observed in [20] and [21]. One of the most promising area of additive manufacturing is metal additive manufacturing. It has more than 30 different technologies, including powder bed fusion, binder jetting, and directed energy deposition [22]. These technologies are used to produce parts that are strong, durable, and heat-resistant, making them suitable for industrial applications. The vast number of technologies makes metal AM a versatile tool for a wide range of applications. However, it also means that it can be challenging to choose the right technology for a

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specific application. It is important to understand the capabilities and limitations of each technology and subcategory to make an informed decision [23].

2.2. Educational point-of-view of the technologies and digital transformation in manufacturing

Global manufacturing and production chains are focusing more and more in embracing factors of digitalization in different areas targeting increased efficiency and flexibility in their operations. The fast transformation speed of modern manufacturing technologies sets new kinds of challenges to the education of such technologies to educate experts who can adopt the technologies in real-life. According to The Global Smart Industry Readiness Index Initiative [24], the manufacturing sector needs to emphasize education and training of the workforce to meet the requirements of digitalization and the development of company strategies. This kind of transformation in the operational structure increases the competitiveness of companies in the digitalization race. Digital transformation covers areas such as information processing, computation and connectivity within company operations. It offers a platform in distributing information in a new way which boosts collaboration possibilities within digital networks. This kind of environment in the manufacturing sector offers new ways to apply modern manufacturing technologies and create a positive atmosphere for innovation and improved efficiency with perspective to competitiveness, as in [25].

The digital transformation related especially to higher education (HE) needs strategic planning to be able to fulfil the needs from modern manufacturing technologies and overcome obstacles in arranging the required workforce training and education. One key issue is for higher education institutes (HEIs) stakeholders to develop digital skills in personal and operational level. This increases the digital competitiveness of the HE organization and enables improved possibility to arrange high quality education. Digital trends such as artificial intelligence (AI), machine learning, cloud computing and big data are factors required to be implemented in arranging the education as the same factors are spreading also in the manufacturing sector in technological level. Strategic digitalization planning in education requires systematic operation such as roadmaps which enables the development in management and HEI business operations. [26]

2.3. Knowledge and knowledge transfer in different forms

Knowledge can be defined as explicit formal knowledge that can be documented or as tacit knowledge where personal experience or organizational experience can be embedded and that is often referred as know-how. Knowledge transfer can take place as series of actions that include identifying the knowledge, capturing the knowledge and utilizing the knowledge. In this respect knowledge transfer also benefits from interaction and sharing of information between different actors ([27], [28] etc.). Work integrated learning (WIL) philosophy, where students learn outside the university while working in company environment [29] on real company cases is one way of bringing new knowledge of AM to the industry. Students have learnt the theoretical background in the university courses, and they learn to apply it in the industry with real industry cases where one needs to be able to find solutions and to argument the choices. This approach supports the knowledge transfer of new methodologies to the manufacturing of industrial applications. WIL is also about creating new knowledge that results from complex, new and real industry need problem solving. The transfer across university and organizational boundaries is primarily transfer of knowledge that originally had been acquired in one specific situation or context to other contexts [30]. The core idea of WIL is that employability of graduates will increase if they are able to integrate theoretical and academic studies with work-experiences in their respective educational fields [29]. Knowledge is acquired by working with partner companies on challenges that require solutions. University can become a partner that is appreciated for problem-solving in its region. This type of co-operation in knowledge transfer requires the creation of trust between company and university as well recognition of expertise of the other. These act as the basis for working co-operation.

2.4. Processes of cooperation to enhance knowledge transfer

According to Luomaranta et al. [31], value-focused approach to adopting AM and innovating means understanding the value that new technology can create to all organizations of supply chain involved. According to [32], adoption of AM in companies in industrial scale use can be incremental innovation in one industry, whereas in another industry it represents radical innovation. Also, the ways in which AM is used in companies can represent radical innovation, incremental innovation or disruptive technology e.g., producing complex parts. In actual company processes, it means adoption of AM on different levels; concept level, process innovation level as well as product innovation level, as e.g., in [33]. All levels of taking advantage of AM also require different ways of knowledge transfer into a company – people management. Businesses are part of value chains or value networks and the whole development path of the industry can be a driver to the development needs or need for innovativeness in a company. [34] For knowledge transfer to be successful within an organization, it is imperative that learning be recognized as a critical component of overall success, as in [35] and [36]. Despite its importance, Gino and Staats [37] have identified several challenges that can impede the learning process. One challenge is the fear of failure, which can trigger negative emotions and cause individuals to avoid mistakes at all costs. As a result, projects may be structured in a manner that does not allow for experimentation, with little time or resources allocated for trial and error. This approach can impede an ability of organisation to develop new capabilities and take appropriate risks. Instead, managers should cultivate a culture that tolerates failure and encourages open discussion about it. [38] Another challenge is the overreliance on past performance. Relying too heavily on previous successes may inhibit innovation and limit the potential for growth. Additionally, a lack of reflection can impede the learning process. In an environment where workers are expected to be "always on," there may be limited opportunities for individuals to reflect on their performance and identify areas for improvement. Encouraging reflection is essential for enhancing learning and development within an organization, as e.g., in [39] and [40].

3. Case studies of knowledge transfer in training

This article analyses AM knowledge transfer in two case-studies in Finland for training industry representatives. One example presents Northern university of applied sciences learning environment and the other introduces a university project from Southwest Finland where also a new technological means of introducing AM to the industry is tested.

3.1. Case-study 1: Lapland University of Applied Sciences new Master´s degree programme for training workforce

Lapland University of Applied Sciences in Finland (Lapland UAS) started to develop a new Master´s degree program in 2022 called “Master of Renewing Industry” based on the needs coming from Northern Finland labour market and companies. The purpose for the degree program was to provide training for workforce during one academic year and transfer knowledge about modern manufacturing technologies to companies. In Finland, traditional engineering Bachelor´s degree length is four years and 240 ECTS in length. Therefore, UASs can provide Master´s degrees in engineering with 60 ECTS during one year [41]. Main aim for the new education was to provide efficient knowledge transfer from education to companies and therefore support companies in their development of technological expertise and competitiveness. The planning work consisted of mapping out future needs for training engineers for the year 2030-2035 [42] which aimed to point out required professional skills in educating future engineers. In addition, Lapland UAS collaborated closely with Northern Finland companies in mapping out the needs of the companies for the education. This led to the creation of the themes for the degree program. Themes were constructed around the concept of twin transition, digitalization and sustainability in company operations. Other important themes were modern manufacturing technologies, strategical leadership in companies, modelling and simulation of industrial processes and identification of technological development possibilities, just a few to mention. This kind of short-term education is a good example how higher education institutes (HEI´s) can support companies in their pursuit of developing their workforce expertise to match the demands coming from the fast development of technology.

3.2. Case study 2: Industrial training of additive manufacturing by using virtual tools in Osuu ja Uppoaa project

In the ongoing Osuu ja Uppoaa project (August, 2021 – July, 2023) funded by the European Social Fund at the University of Turku, the understanding of industrial AM is being brought to small and medium-sized enterprises through VR technology [43]. The operational area is Southwest Finland. The training is structured around a combination of theoretical lectures delivered by researchers from the Department of Mechanical Engineering at the University of Turku and practical demonstrations provided by companies specializing in AM services. These practical examples illustrate the various stages of the AM processes and showcase the final products. [44] The training materials are divided into short micro-learning units, allowing users to navigate between them seamlessly. The content is meticulously designed in accordance with micro-learning principles, as shorter modules delivered through VR goggles offer enhanced user-friendliness. Additionally, incorporating brief, independent learning sessions allows easy integration into the daily work routine. Employing VR goggles as the training platform aligns with the concept of micro-learning, benefiting from its technical simplicity. Using VR goggles simplifies the training experience by eliminating the need for complex login procedures or application downloads, allowing users to seamlessly engage in the training without wasting excessive time.

4. Results and discussion

4.1. Case-study 1: Lapland University of Applied Sciences new Master´s degree programme for training workforce

Lapland UAS has a concept called Smart Lab which integrates three different themes together regarding manufacturing. Smart Lab is concentrated around FESTO Cyber-Physical Factory (CP Factory) which provides digital manufacturing concept to mechanical engineering education. The environment is being used both in Bachelor and Master level of engineering. Smart Lab includes also additive manufacturing and automation laboratory (pneumatics and hydraulics). Main purpose of the environment is to provide education combining different manufacturing themes and actors. One key issue is to enable company participation in the function of the laboratory environment. Companies can participate e.g., by bringing own project work topics or assignments for development. Through workshop actions, companies can also use the environment physically in participation with Lapland UAS mechanical engineering degree. This is enabled through different partnership agreements which ensure close collaboration with actors from different areas. The basic concept can be seen in figure 2.

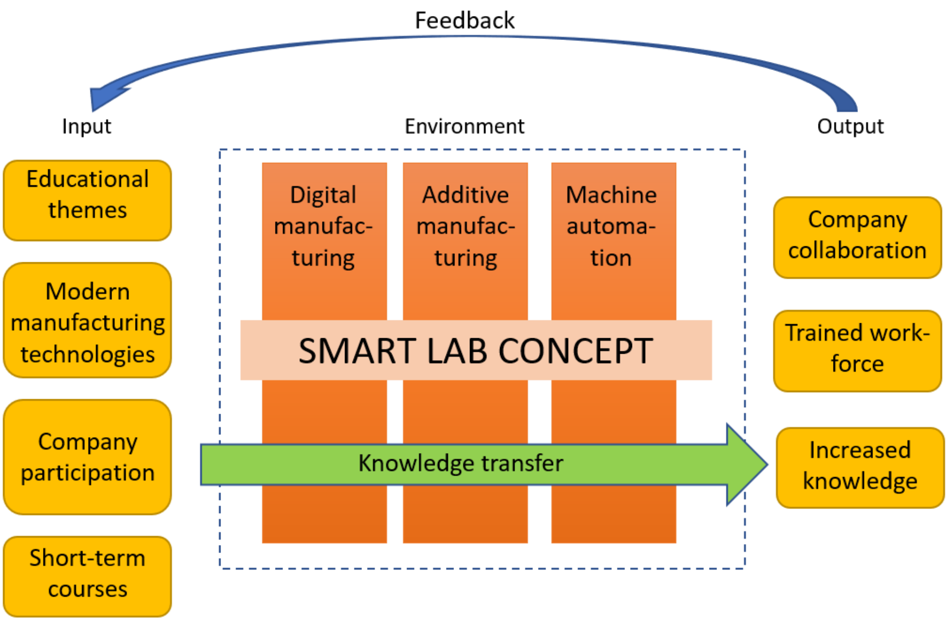

Figure 2. Lapland UAS Smart Lab concept as knowledge transfer enabler.

As seen in figure 2, the Smart Lab concept works through three different elements. In input, traditional engineering education themes from modern manufacturing technologies provide the necessary platform for the training. Company participation (through their own projects and assignments) form the actors functioning in the laboratory environment. The education and training can be tailored e.g., as short-term courses based on company needs and wishes. In the environment, the Smart Lab concept provides all the necessary surroundings for physical laboratory work and education of the actors. This can be built through the three different themes (separately or by combining e.g., digital manufacturing and additive manufacturing). In output, the environment has produced different elements through knowledge transfer. The concept enables results in a form of increased company collaboration, trained workforce (either through graduated mechanical engineering students or trained company personnel) and increased knowledge. This element of knowledge as an output benefits companies through identifying the possibilities of utilising modern manufacturing technologies. This can lead to increased productivity as the possibilities are used in operational and strategical development in companies. One important element of the model is collecting feedback in the output phase. E.g., as companies function in the SmartLab environment (e.g., in a short-term course), it is important to collect feedback from the participants for development of the input phase. This improves the equivalency of what the SmartLab concept offers to companies vs. the needs of the companies.

4.2. Case study 2: Industrial training of additive manufacturing by using virtual tools in Osuu ja Uppoaa project

Information on the free AM training via VR Goggles has been shared through local media, social media (such as the Mechanical Engineering Department of the University of Turku on LinkedIn), participation in various training and business events related to new technologies, and articles written in the industry magazine (Welding Technology Magazine) about the training. In addition to these actions, pilot training material has been presented at the Turku University of Applied Sciences and student organization events. Despite of direct and indirect interactions in project with numerous key personnel in SMEs, minimal interest from the side of companies was shown. Remarkable is that every interested company already has experience in additive manufacturing. According to survey done in this study, students who had some previous contact with additive manufacturing, either through their studies or personal experiences, were more interested in learning about the technology.

5. Conclusions

The aim of this study was to identify the factors for efficient knowledge transfer and education in laser-based manufacturing technologies, particularly in engineering education, to ensure the manufacturing industry can effectively utilize and implement these technologies in their operations, thus contributing to the digital transformation of traditional manufacturing industries. In this study, two learning environments were discussed and the learning ideas of them explained. The Lapland UAS Smart lab concept has now been operational for over two years and experiences have showed that the environments functions well as a supporter of digital manufacturing skills for engineering students. The environment promotes the connection of different themes such as digital manufacturing and storage control, machine vision, automatic process control and the connection of other manufacturing technologies such as AM. AM has been used in the environment for developing products to the manufacturing system. The students have been able to design and manufacture different assemblies where the parts can be processed through the CP factory enabling e.g., modularity in the manufacturing process. This gives new kind of approach methodology to view real-life manufacturing processes in educational environment. Companies have at the same time gained new knowledge related to AM and its possibilities in their own operations and they are willing to continues this type of co-operation with the UAS. As the students graduate to companies, they can adopt the knowledge transfer elements from modern themes and adopt them while working in companies. One important factor in ensuring the quality of knowledge transfer is collecting feedback. As the different operators such as companies and other participants participate to the SmartLab concept, it is imporant to collect their feedback afterwards to further improve the contents of the education and respond better to the needs of the operators.

In this study, it was also found out that learning environments can be integral part of knowledge transfer, learning environments can at the same time be combining industries with university research and education. The learning environments studied and presented in the article are pioneering methods of knowledge transfer in their particular geographical areas in Northern Finnish UAS and in Southwestern Finland. In both cases new knowledge is transformed in the companies via university-company collaboration, trained and skilled workforce as well as increased knowledge. The digital learning environment supports knowledge transfer by utilizing various channels such as local and social media, participation in relevant events, articles in industry magazines, and presentations at educational and student organization events, to share information about additive manufacturing training via VR goggles, as tested in Osuu ja Uppoaa project, with students who had prior exposure to additive manufacturing displaying a higher interest in learning about the technology.

In the future, studies around comparative analysis of learning environments, long-term impact of university-industry collaboration and evaluation of digital learning tools will be carried out. Conducting a comparative analysis of different learning environments, such as Lapland UAS Smart lab and similar setups in other regions, to assess their effectiveness in facilitating knowledge transfer and education in laser-based manufacturing technologies. This study would help identify the strengths and weaknesses of various learning environments and provide insights for further improvement.

6. Author contribution

During the preparation and writing of this work no AI based tools were used. Authors reviewed and edited the content of this work independently and take full responsibility of this contribution.

All authors drafted the idea of this publication. Further brainstorming was executed by all authors. The actual drafting of the concept of knowledge transfer in the education of engineers approach introduced in this article was discussed, commented on, and modified by all the authors.

Heidi Piili participated in the literature review from the areas of additive manufacturing, additive manufacturing education and training, and knowledge transfer of additive manufacturing knowledge. She was responsible for sub-chapter “2.1. Laser-based manufacturing technologies”.

Anna Huusko has participated in this publication from areas of learning, education and industrial training and discusses obstacles that industrial training can meet. She was also responsible of sub-chapter “3.2. Case study 2: Industrial training of additive manufacturing by using virtual tools in Osuu ja Uppoaa project” and sub-chapter “4.2 Case study 2: Industrial training of additive manufacturing by using virtual tools in Osuu ja Uppoaa project”.

Anu Kurvinen has participated in this article from the areas of learning, education and training and discussing how knowledge transfer is taking place in industry. She was responsible for Literature review’s sub-chapters “2.2. Educational point-of-view of the technologies and digital transformation in manufacturing”, “2.3. Knowledge and knowledge transfer in different forms” and “2.4. Processes of cooperation to enhance knowledge transfer”.

Ari Pikkarainen participated in the literature review from the areas of additive manufacturing and knowledge transfer especially from the educational point-of-view. He was responsible for sub-chapter “3.1. Case-study 1: Lapland University of Applied Sciences new Master´s degree programme for training workforce” and for sub-chapter “4.1. Lapland University of Applied Sciences new Master´s degree programme for training workforce”. He also contributed to chapter “5. Conclusions” related to previous chapters. Ari Pikkarainen is also the corresponding author of this publication.

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