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# Preliminary study of knowledge transfer aspect in the creation of a framework for education and training of digital manufacturing technologies

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

[1] Department of Mechanical Engineering, Faculty of Technology, University of Turku, Turku, 20520, Finland
[2] Department of Business, International Business, LAB University of Applied Sciences, Lappeenranta, 53850, Finland

anu.kurvinen@lab.fi

**Abstract.** Digitalization is changing the industry. As this change accelerates its speed, it also requires a transformation process where knowledge transfer between industry and research institutes play a significant role. There is a need to be more fluent, flexible, and efficient in order to get the latest research results into industrial implementation as quickly as possible. The challenge in knowledge transfer is that its speed in the current stage is too slow compared to the speed of development and changes required by digitalization of traditional manufacturing industries. The motivation for this study is the gap in knowledge transfer. One emerging digital transformation is the establishment of modern digital manufacturing technologies, e.g., additive manufacturing (AM). There are different approaches to supporting the industry in this transformation. Knowledge transfer can happen, for example, through education (e.g., master students) and industrial training, but also the fluent transfer of the latest research results from research institutes to companies is needed. University education needs to support the requirements of the manufacturing industry by providing future experts with skills to smooth the transformation process and bring novel technology applications, such as AM, to industrial-scale use. The article discusses how university education can support future competence-building in the industry. Similar needs are also present in industrial training, which universities often provide. Both education and training need to be improved from fundamental approaches to explain how this new knowledge should be created, i.e., how knowledge transfer happens most efficiently. The outcome of this article is the basis of the framework for education and training of digital manufacturing technologies by using modern learning methods and tools. More detailed pedagogical and knowledge transfer models can be developed and applied when this framework is created.

## 1. Introduction

Additive manufacturing (shortened as AM), or more commonly 3D printing, consists of wide variety of different modern manufacturing technologies. AM is based on direct fabrication of a digital 3D model to a final product which is fabricated adding material layer by layer. This is where term AM has its origin. It is not only material what is added, but it is also value, properties etc. which are added. AM enables production of different and even better products compared to conventional manufacturing technologies. As in many cases, AM is a new method introduced in production, one of the challenges for design processing and engineers, is to identify suitable applications for AM. When successfully

applied, AM can help companies to create additional value in e.g. new product development and order fulfillment processes. [1]
An estimation of potential of AM can be gathered by considering the potential of laser cutting, which is one of the most widely used modern manufacturing technologies, as in [2] and [3] With a market value of around four billion euros and an annual growth rate of approximately 10%, laser cutting has been a significant technology for over four decades. However, the emergence of AM and 3D printing promises radical advancements in the production of three-dimensional parts, mirroring the transformative impact of laser cutting on flat sheet products. Currently, laser devices utilized in AM constitute merely 1% of all laser devices employed across various fabrication technologies worldwide. This statistic highlights the growth potential for lasers in AM in the coming years. Even with a conservative estimate, it is highly likely that the technology will experience a minimum of 100% growth, making it remarkable in manufacturing, as e.g. in [4], [5] and [6].
Metal AM is a decades old manufacturing method which has grown to a point where it is a potential way of manufacturing for example for certain aviation and medical applications. AM in general was originally used for prototyping purposes, but nowadays it is mainly used for fabricating of functional parts. AM is utilized in many industries globally, but still lacks for example quality assurance systems ([7] [8] etc.). Utilization level of metal AM is presumable lower than it could be in Finland. Lack of knowledge about possibilities of metal AM might be a reason for that. Finding suitable parts for metal AM also requires lot of knowledge which has not been taught to most engineers during their education. Therefore, there are companies utilizing metal AM on a daily basis whilst some have never tried it. [9]
Education and training play a crucial role in the successful industrial implementation of modern technologies. Education in this study means education in universities, and training is industrial training. When both the new generation entering the workforce and those who have been in it for some time comprehend the potential and limitations of these technologies, it opens opportunities for rethinking product design. AM and 3D printing offer freedom to design new products, new methods of production and generally new ways of doing things. The vast potential of product design serves as a catalyst for the widespread adoption of AM and 3D printing, as a deeper understanding of the technology allows for innovative and optimized designs that leverage the capabilities of these advancements, as e.g. in [10], [11] and [12].
AM and 3D printing present a significant opportunity for Finland and its industrial sector, leveraging the strong industrial expertise and proficiency in information and communication technology (ICT) in country, as concluded in [13] and [14]. Authors have concluded to discuss in this study both AM and 3D printing, as both industrial applications (additive manufacturing) and consumer applications (3D printing) are included to this theme in upper level. To fully harness the potential of this technology, companies must explore the suitability of their products for AM and 3D printing, as well as test product enhancements and consider complete redesigns. Equally important is providing education and training opportunities for the existing workforce, enabling successful industrial implementation. This holds particular significance for Finland, as it strives to maintain its competence in global markets. By equipping both new and experienced professionals with the necessary knowledge and skills, Finnish industry can maximize the benefits of AM and 3D printing, fostering innovation and competitiveness in the global arena (e.g.in [10], [15]).
A number of publications related to topic of this study were surveyed via Scopus with different keyword combinations. Scopus is a comprehensive database covering a wide range of academic disciplines, ensuring it to be trustful database for literature survey.

## 2. Aim, purpose and methodology of this study

The aim of this study is to address the gap in knowledge transfer between research institutes, universities and industry amidst the rapid digitalization of traditional manufacturing industries, as in [16] and [17]. The focus is on supporting transformation of industry through education, such as master's programs, and industrial training. These education means in this article all AM education provided by universities (also universities of applied sciences, UASs) or other similar institutes, and it is called university education. The study explores how university education can equip future experts with the skills needed for the implementation of modern digital manufacturing technologies, like AM, at an industrial scale. It emphasizes the need for improved education and training approaches that efficiently facilitate knowledge transfer. The study lays the groundwork for a framework to enhance education and training

in digital manufacturing technologies, highlighting the importance of further research and development in this area. Discussion on right balance between studying explicit content that will, depending on subject, become easily out-of-date and meta-skills that are useful but at the same time may leave learners an experience of not learning anything specific has been going on for a long time. Skills that are easy to teach and where learning is easily measured, are skills that are also easily automated, as concluded in [18], [19] and [20]. Demand for AM courses has grown dramatically. Therefore, even complete master's degrees are offered by some universities nowadays. Individual AM study courses are offered by all education levels and low-cost 3D printers can be found even in elementary schools. However, industrial training should also be offered in the same scale in order to increase utilization of AM. [21]
This study is scientifically important as it addresses the crucial issue of knowledge transfer between research institutes and the industry in the context of digitalization in traditional manufacturing industries. It provides insights into the role of education in equipping future experts and emphasizes the need for improved approaches to facilitate efficient knowledge transfer. The study establishes a foundation for further research and development in enhancing education and training in digital manufacturing technologies. The industrial importance of this study lies in its potential to bridge the gap in knowledge transfer between research institutes and the industry during the digitalization of traditional manufacturing sectors. By focusing on education and training, the study aims to equip the industry with skilled professionals capable of implementing digital manufacturing technologies effectively.
Background and basis of framework for this study was done as literature review. A Scopus survey was carried out also to see number of research articles related to this study between 2010-2022. In this article survey following searches were done: "additive manufacturing" OR "3D printing", "engineering" AND "additive manufacturing" OR "3D printing", "industry" AND "additive manufacturing" OR "3D printing", "education" AND "additive manufacturing" OR "3D printing", "learning" AND "additive manufacturing" OR "3D printing", "knowledge transfer" AND "additive manufacturing" OR "3D printing". Based on the survey result, the research on additive manufacturing/3D printing and engineering has increased during the period of 2010--2022, which reflects the fact that interest towards industrial use of AM and its different variations has been increasing. At the same time there is a corresponding development and increasing trend in research concerning education, learning and training of AM. When looking for studies handling knowledge transfer in AM, there were only 1-5 research publications annually between 2010-2015. When approaching year 2019 and after that there is a clear increase in research concerning knowledge transfer. This shows that understanding the full potential of a novel manufacturing methodology to a company requires a more in-depth learning and adoption of new knowledge on different levels of organization. In this article different ways of learning and acquiring new knowledge are discussed.

## 3. Learning in education and training of additive manufacturing

AM and 3D printing are revolutionary technologies poised to shape the future of global industries. These emerging technologies, including additive manufacturing, have already begun to disrupt the manufacturing sector, unlocking potential for previously unimagined applications. Across Europe, several universities are offering master's degree programs focused on AM. These academic programs are essential in cultivating the next generation of experts who will drive innovation and advancement in AM and 3D printing. By equipping students with specialized knowledge and skills, these universities are paving the way for the widespread adoption of these technologies and fostering a competitive edge for industries in the global business arena. As AM continues to evolve, the demand for educational programs in this field is likely to grow, fueling further advancements and unlocking even larger possibilities. These are deduced e.g. in [3], [22], [23] and [24].
Deloitte and The Manufacturing Institute [25] conducted a study among US manufacturing industry, in order to reveal the future of manufacturing work. According to the study, there is a widening gap between the amount of skilled new employees and the jobs that need to be done. [25] University pedagogics and range of available studies are thus in key role in formulating the path towards potential exploitation of the AM technology in industry applications ( [26], [27] etc.)
As this study focuses on educating a field of technology that is expected to some extent change and develop the traditional manufacturing industry, there is a need to think pedagogical models that enable learning and development but at the same time encourage creativity and innovativeness. In the modern world, there is lot of information available. The challenge is that, one has to be able to think critically

and have skills to synthesize and put the information into action in a wise way. [28] According to Fadel et al. [29], there is also an important dimension needed – meta-learning. Meaning that there are internal processes required for learning to take place, namely reflection and adaptation of our learning. The educators have to rethink the methods of learning and the choice needs to be done between teaching skills vs. teaching knowledge, as in [29] and [30]. A summary of the choices to be made in education is presented in table 1. [30]

| Teacher-directed | Learner-centered |
|---|---|
| Direct instruction | Interactive exchange |
| Knowledge | Skills |
| Content | Process |
| Basic skills | Applied skills |
| Facts and principles | Questions and problems |
| Theory | Practice |
| Curriculum | Projects |
| Time-slotted | On-demand |
| One-size-fits-all | Personalized |
| Competitive | Collaborative |
| Classroom | Global community |
| Text-based | Web-based |
| Summative tests | Formative evaluations |
| Learning for school | Learning for life |

**Table 1.** Comparison of teacher-directed and learner-centered approaches. [30]

In an ideal case, the process of learning enables the student to test or experiment the theories learnt and reflect the learnings with the lecturer or coach. That way the process of learning and new knowledge creation can take place.

### *3.1 Lifelong, life-wide and life-deep learning*

Lifelong, life-wide and life-deep learning is very often mentioned as crucial part of education, training and generally working life in the future [31]. According to UNESCO, lifelong learning means the integration of learning into various aspects of life, accommodating people of all ages and contexts. It includes diverse learning activities within different settings, such as family, school, community, and the workplace, utilizing both formal and informal educational methods to address a wide range of learning needs and demands. [32]

The ideal learner is someone who is flexible and motivated to continually develop themselves, particularly in response to evolving work demands or shifts in their profession. Lifelong learners view professional development as both a challenge and an essential aspect of modern work life, recognizing its significance in staying relevant and thriving in their careers. [33] Lifelong learning is very often mixed with life-wide learning. Lifelong learning consists of informal/formal learning in context of professional learning, whereas life-wide learning includes whole life with all its aspects. These are discussed e.g. in [34], [35] and [36]. Hietanen and Rubin [37] conclude that education and training should be discussed in context of human lifespan and situations in human life, as whole human life is one kind of learning situation. This idea is shown in figure 1.

The presence of a third dimension in lifelong and life-wide learning, known as life-deep learning, is highlighted by [31], [38] and [39]. This concept is intricately linked to the holistic and multilayered development of individuals, encompassing the formation of their lifespan in its entirety, including the diverse changes, transitions, and challenges they experience along the way. Life-deep learning emphasizes a comprehensive and profound approach to personal growth and development. Lifelong, life-wide and life-deep learning can be shown as three-dimensional illustration as figure 2 shows.

Lifelong, life-wide and life-deep learning are consequences of changes in todays´ working life. Digitalization and modern technologies require that learning should happen in all aspects of human life. If not, it will lead to lowered level of skills needed in work life and in worst case to digital exclusion. [39] It can be concluded that constant changes in work life and skills needed there is permanent situation nowadays. This can be observed from expectations set to education and industrial learning of AM and 3D printing. This education and training should in first hand be able to provide such tools for students and trainees that they can update frequently their know-how proactively and independently. [40]

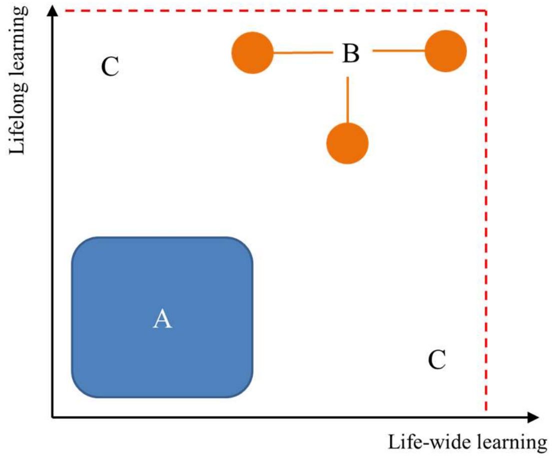


**Figure 1.** Lifelong and life-wide learning cover whole human life. A = From comprehensive school to university, B = industrial training in work life, C = human lifespan. [37]

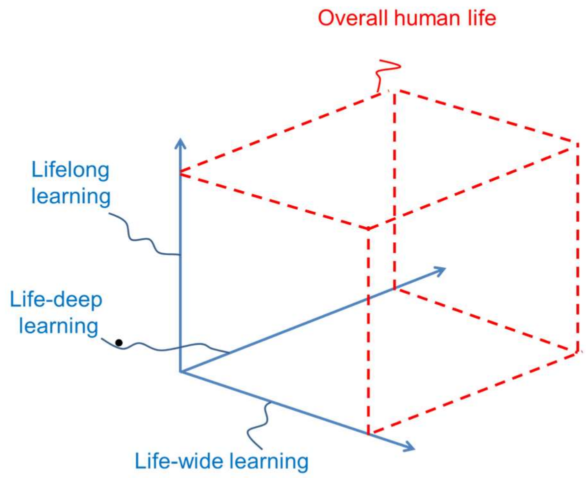


**Figure 2.** Lifelong, life-wide and life-deep learning is widened to concern lifespan, situations and emotions of human being and this way they form three-dimensional integrity. [36]

### *3.2 Creative thinking*

According to [10] and [12], role of education is important when a new technology is industrially implemented. Development, planning and execution of education for AM and 3D printing is challenging as this area develops very fast. Planning of education for AM and 3D printing requires collection pieces of data from various sources. [12]

Introduction of new technologies or new ways to utilize them requires encouraging innovative thinking and also creative thinking in a company [41]. New technology cannot just be copied between industries and organization, also innovativeness and creation of new type of solutions is important [42].

Education plays a crucial role in the industrial implementation of new technologies. Additive manufacturing and 3D printing offer opportunities for designing new products and revolutionizing production methods. However, the rapid development of this field poses challenges in the development, planning, and execution of education programs, as in [2] and [24]. To effectively plan education for AM and 3D printing, it is necessary to gather data from various sources to stay abreast of the latest advancements. Incorporating new technologies or innovative ways of utilizing them requires fostering innovative and creative thinking within companies. It is not enough to simply copy technologies between industries and organizations; it is essential to encourage innovativeness and the creation of novel solutions. These are further discussed in [43] and [44]. By incorporating these principles into education, students are motivated to engage in lifelong, life-wide, and life-deep learning. They are encouraged to continuously learn and apply their knowledge and skills in various contexts, expanding their learning experiences beyond traditional classroom settings. [45]

Companies are looking for ways to add value to the product development and order fulfillment processes by introducing AM in the production. Before implementing reliable identification and selection processes to find out where AM promises the most added value. A model of value clusters of AM has been studied [1]. The study mapped e.g. design strategies and evaluation matrix for assessing the parts to be produced by AM. The proposed method for value-driven part identification and selection was applied and evaluated in various technology transfer projects between AM experts and experienced engineers in the industry both in minor design change cases and major design changes. Engineer ingenuity to identify suitable parts was combined with AM expertise. In the study, it was proposed that selecting parts manufactured by AM consists of two phases. First, identifying parts that might benefit from a change to additive manufacturing. Secondly, selection phase that evaluates the identified parts and leads to selection of ones that best fit by the properties and features of the application. This study example confirms that modern AM education can not only rely on introducing copying the technology itself but also needs learner-centered methodologies that encourage creativity thinking in the use cases. [1]

## 4. Discussion

In the era of Industry 4.0, robots and artificial intelligence are transforming the economy. There is something that cannot be replaced by automation, that is creativity. According to the study conducted by IBM, creativity on all levels of actions, is a way to respond to the complexity of the business environment of current times and turn the challenges to advantages. [17] The ongoing development of pedagogical methods in AM and 3D printing provides an opportunity to foster creativity and thinking beyond traditional manufacturing approaches. To enhance creative thinking of students, it is crucial to include a more focused emphasis on innovation and problem-solving in their courses. Practical exercises and concrete steps can help students gain hands-on experience and apply their skills effectively. It is obvious that there is the profound impact of digitalization on industries and it underscores the crucial role of knowledge transfer between industry and research institutes in enabling the transformation process. There is clear need for a more efficient and agile knowledge transfer approach to quickly implement the latest research findings into industrial practices. [16] However, the current speed of knowledge transfer lags behind the rapid pace of development required by digitalization in traditional manufacturing sectors, presenting a significant challenge.

Results of Scopus survey done in this study show that there is a constant, and steady increase in research related to additive manufacturing or 3D printing during past ten years (2010-2022). At the same time, it can be stated that there is an increase in the research of education and learning of AM and 3D printing. Knowledge transfer in AM and 3D printing is relatively new research topic according to this Scopus search, but there is some research already done in the area. This reflects the fact that traditional education and training methods also need to be complemented with new methods and learning environments that support knowledge transfer of research results to the use of manufacturing industry.

There is a gap in knowledge transfer, particularly in the context of emerging digital manufacturing technologies like AM, as this was shown in literature survey done with Scopus. This issue needs further study. It is important to provide new approaches to support the industry during this transformation, including education (such as through master's programs) and industrial training. University education plays a vital role in equipping future experts with the necessary skills to facilitate the smooth integration of novel technologies like AM into industrial-scale applications. [46]

Both education and training need improvement, with a focus on fundamental approaches that explain how knowledge transfer can happen most efficiently. This is why there is a need of framework for education and training in digital manufacturing technologies. The framework proposed in this article is for education and training in digital manufacturing technologies, aiming to improve knowledge transfer efficiency and provide a basis for further research and the development of pedagogical and knowledge

transfer models. [22] Engaging students in real-world problem-solving tasks assigned by companies can further stimulate their creativity and motivation. [47] By working on these assignments, students develop a deeper understanding of how their skills can be applied in practical situations and are encouraged to think outside the box. Expanding the scope of study courses to include students from diverse disciplines beyond mechanical engineering can also enhance creativity. By forming multidisciplinary groups, students can benefit from different perspectives, knowledge, and skill sets. Collaborating with peers from various backgrounds fosters creativity and enables the exploration of unconventional solutions that may not have been considered within a single discipline.
In Finland, there is active cooperation between AM industry and research which has been developed during last years to be closer than ever. For example, there are ecosystem of Finnish AM Ecosystem (FAME) between industry and research was established 2020, and it has several companies in field of AM. FAME has several AM projects going on between industry and research institutes, this is further introduced in [48] and [49]. There is a rich variety of companies operating in different parts of AM sector – as AM production companies, various type of equipment providers from AM printers for metal to biotechnological technology as well as programming companies. COVID-19 pandemic challenged global supply chains and enabled creation and implementation of emerging innovative ideas. These are discussed e.g. in [9], [50] and [51].

## 5. Conclusions

The aim and purpose of this study was to address the gap in knowledge transfer of AM technologies between research institutes and the industry organizations. The study was done as literature review study in Scopus. Number of published research articles handling topics 3D printing, AM, knowledge transfer and training of the technologies was analysed as a Scopus study. The time range the articles were published was 2010-2020. Main results of the study are that the meaning of education in AM and 3D printing, and also sharing the knowledge of different methods has increased heavily during the analysed period. The number of research articles handling knowledge transfer analysis also showed that knowledge transfer as a research topic is not yet as deeply investigated, and assumedly thus meaning of it not as deeply recognized. The article survey shows that development of pedagogical methods is an ongoing process that evolves over time. AM and 3D printing are methodologies where all the application areas are not found yet.
As a result, to the main purpose of the article, “finding solutions for knowledge transfer aspect in the creation of a framework for education and training of digital manufacturing technologies”, it can be stated that knowledge transfer process is a complex process. When developing training organized for industry representatives, involving different company internal groups participating the design processes and making the evaluations of customer and business values of applying AM in the production could be one solution enforcing knowledge transfer. This in general gives the requirement to learn creativity and ability to think outside the traditional manufacturing industry schemes. Collaboration between industry, universities and research institutes in AM in Finland continues to be all the time closer, fostering a diverse range of companies across the AM sector. These companies encompass AM production, equipment providers for metal and biotechnological technologies, and programming firms. The COVID-19 pandemic disrupted global supply chains, prompting the birth and adoption of novel, ingenious concepts.
In the future, one possibility to strengthen the knowledge transfer, creativity thinking and innovativeness of the students, would be to include even a clearer step of innovation creation and problem-solving to the study course since the fact that the lecturers are telling about this, is not making the idea concrete enough to all the students. Other ways of increasing creativity among university students could be trying to get some company-given tasks to be the student groups which would in some cases give more cause to real problem-solving assignment. Also increasing the interest of the study course towards student groups outside mechanical engineering and forming more multidisciplinary groups, when possible could be one solution.

## 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 framework for education and training of digital manufacturing technologies introduced in this article was discussed, commented on, modified and concluded by all the authors. All authors have contributed to the literature review part of the article, Chapter “2. Aim, purpose and methodology of this study” and Chapter “3. Learning in education and training of additive manufacturing” introduction. All authors have contributed to chapter “4. Discussion” and “5 Conclusions”. Heidi Piili was responsible for sub-chapter “3.1 Lifelong, life-wide and life-deep learning” and the Scopus research. Anu Kurvinen is responsible for sub-chapter “3.2 Creative thinking”. The final draft of the publication was discussed, commented on, edited, modified and concluded by all authors.

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