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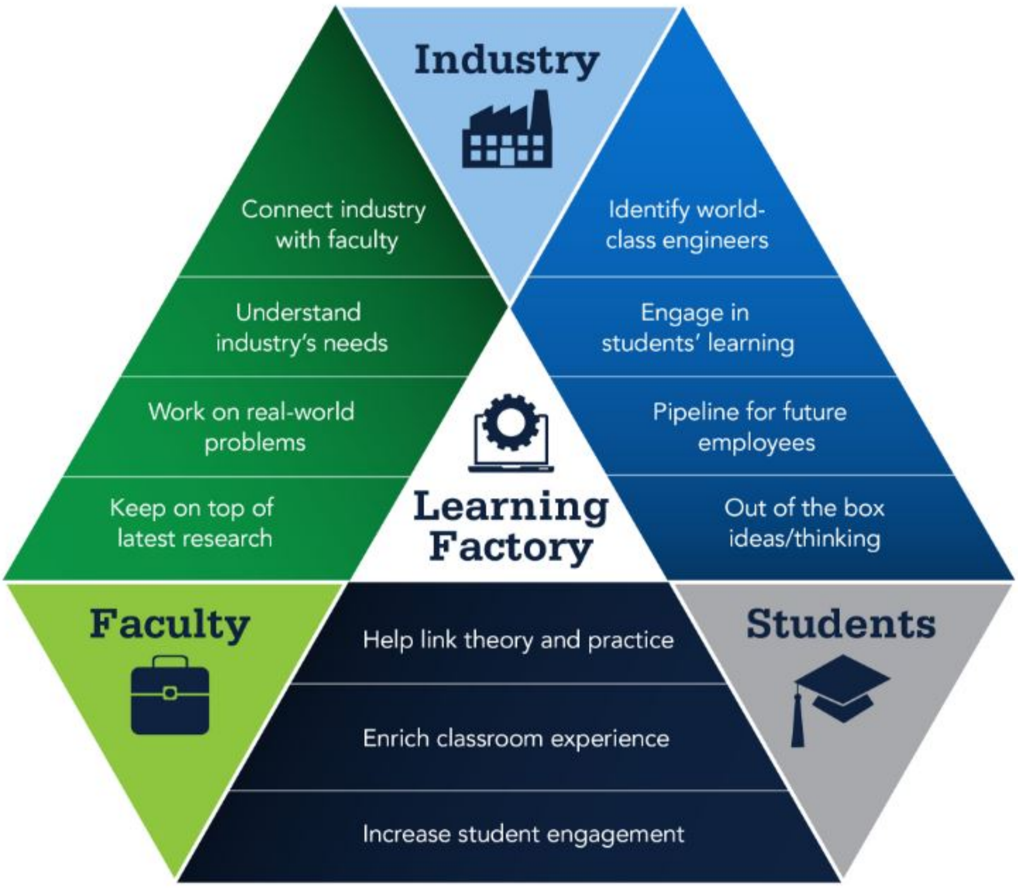

A Literature Review on Learning Factories

Master's thesis in Production Engineering

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Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2018

Master's thesis 2018

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Cover: Learning Factory concept [36]

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Abstract

The Industries of the world are constantly striving hard for increased productivity and to be competent in all aspects . Every company has distinct goals and objectives which are aligned with the strategies for the purpose of achieving success. To meet such great levels of success, it puts a huge pressure on the existing workforce as well as in the future for the companies. The concept of implementing Learning Factories have been found to be an effective way to tackle the issues in providing effective training to the stakeholders involved. It can hence be used for a smooth transformation into the requirements as expected in the Fourth Industrial Revolution.

The scope and aim of the thesis is to conduct a literature review based on the concept of Learning Factories, which has been developed over time through international conferences. The report currently concentrated on the three conferences held over the years 2015, 2016 and 2017. The articles are studied and classified according to different focus areas. An important result of the thesis was to locate the areas where the majority of research was conducted, which in turn helps in understanding the trend of the research being carried out.

The review also looks into the different fields and related topics within the area of study, such as Industrie 4.0, Cyber Physical Production Systems and Smart Factories. The study aims to provide a simple solution to sort and classify the different papers presented in each field so that it s better represented. The grounded theory was used to conduct the review throughout the report.

The articles of the conferences are sorted based on a different criterion to analyze the trend of Learning Factory research in different locations across the world and also based on their types and fields of applications. Furthermore different graphical representations are plotted to analyze the trend in the development of research over the years based on location, scenario and field of application.

The findings points to a more concentrated research being carried out in the Industrial and Academic Scenario. The findings further help us to understand and locate the places where the research on Learning Factories need to be improved, such as the Asian countries where we can see an increase in the manufacturing over the years. It is evident that Germany leads in the research promoting changeable working environments for the future needs.

Keywords: Learning Factories, CPS, Industrie 4.0

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Aswin Kumar Parekattil, Rasim Karukapadath Haffees
Gothenburg, October 2018

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1
Introduction

This chapter is intended to present the reader with the necessary background information regarding this master thesis and also to describe its purpose and goals, furthermore, the research questions are given followed by the delimitations of this research.

1.1 Background

The advanced economies are striving to revolutionize industrial manufacturing due to the shift from mass production to customized production [1]. The current technological advancements have made several industries increase their productivity and this in turn has put more pressure on their competitors [1]. This is the time when all the industries are working towards transforming into Industrie 4.0 and the development of smart factories. This process of transformation comes with a whole new level and a distinct set of skills that are to be expected from the engineers and all the people involved with the process. Hence it is required that a proper and effective method for the education and training of the stakeholders is implemented. According to F. Baena *et al*, Learning Factories have been shown to be effective for developing theoretical and practical knowledge in a real production environment [2]. The concept of Learning factories is of utmost importance, as they are effective tools for the demonstration and training of the personnel involved. The major problem existing today is the lack of educational approaches to provide an experience-based knowledge that can be imparted to the engineer along with anyone associated with the process to meet his skills. A Learning Factory can be defined as a perfect replica of processes or activities which add value to the industry where formal and informal learning takes place. They are used in educational purposes, research and training in areas of manufacturing, service operations and among several others [2].

1.1.1 The Industrial Revolutions

The concept of Learning Factories can be introduced and defined convincingly if we study the developments and changes that have led to the invention of such a concept over the years. The industrial revolutions have always brought forward major innovations and technological developments in the field of manufacturing over the past century. Each industrial revolution has witnessed the introduction of new technologies, which has highly influenced the industry world in many ways. An important example being the mass production initiative brought forward by Henry

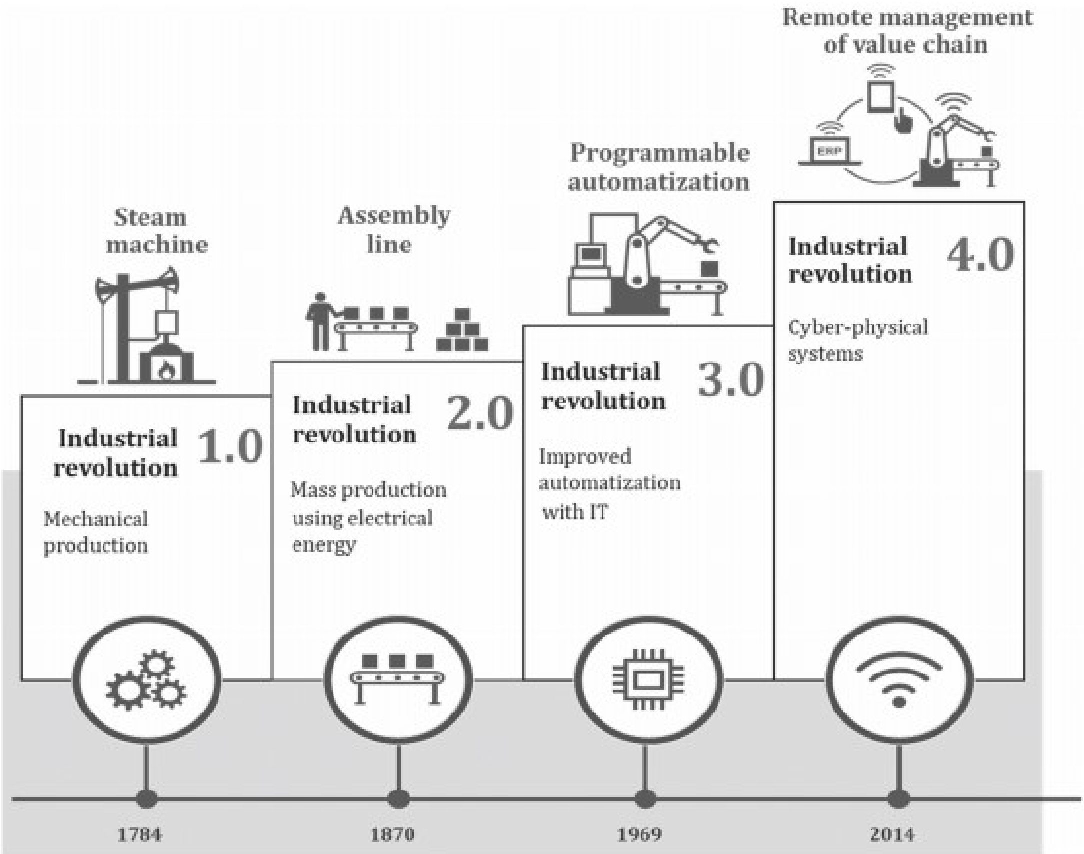

Figure 1.1: Industrial Revolution Impact [3]

Ford, which showcased to the world that mass production of a complex product at low cost could be produced within a factory equipped with an assembly line [4]. Each industrial revolution has its own contribution into bringing the technology and innovations that had led to what we have now [3]. The steam engine was one of the important inventions of all time, which lead to the complete transformation of the textile and transportation industries. The second industrial revolution brought the invention of electricity and subsequently laid the stone for mass production. Henry Ford's concept of mass production of complex products with low cost was applied to several industries which produced a variety of products also making the process much less complex.

The third industrial revolution was called digital age [3].It is so called because it brought the markable change from mechanical, analog electronic to digital electronics today. Finally, the fourth industrial revolution so-called Industrie 4.0 lead the development of the Internet of things (IOT) and artificial intelligence in the industries that we see today. There are several definitions when it comes to the Fourth Industrial Revolution, since it is still in the early development stages. The following section describes the concept as per the literature findings of Baena [2] The Industrie 4.0 concept was developed by academics, industries and the German Government with the objective of strengthening the competitiveness of industrial production through its convergence with Information and communication technologies (ICT). The concept of smart factories and Internet of Things paves the way for the integration of the production equipment and related data sources and is treated as a single integrated system. Some of the notable applications in the manufacturing sector that were developed in this period are predictive maintenance, improved decision making within a short time, improved coordination when considering management aspects and point to point connection between different departments and sectors around industries [3]. Another important part of the Industrie 4.0 are the Cyber-Physical systems. L. Monostori et al. describes the Cyber-Physical System as a system of collaborating computational entities, which are in intensive connection with surrounding physical world and its processes along with providing and using data processing and data accessing services on the internet [5].

1.1.2 The Nine Pillars of Technological Advancements

The major technological advancements in the Industrie 4.0 are explained via the nine pillars of advancements [1]. These areas are described in the section below. In this system, as we have mentioned earlier, all the components, which includes the machines, workpieces, IT, etc are integrated into a single enterprise [1]. These integrated systems (CPS) gather the data, which enables faster, more flexible and more efficient processes to produce better quality products at a lower cost [1]. Nine areas or pillars of technological advancement that laid the foundation for the Industrie 4.0 are [1]:

- **Big data and analytics**
  Analytics based on large datasets have only been recently introduced within the manufacturing industry [7]. Data analytics becomes of utmost importance when it comes to optimizing product quality, saving energy and improving equipment services [7]. In the current scenario which is under the process of transforming into Industrie 4.0, data from several systems and sources is to be analyzed and monitored, for instance, from production equipment systems, customer management systems etc., which will have a direct impact on the real-time decision making of the company [7].

- **Autonomous robots**
  Manufacturers have been using robots for continuous, complex and repetitive tasks. Robots are continuously being upgraded according to the market requirement. Today we can see more autonomous and more flexible robots according to the task. These kinds of robots can work more efficiently and effectively [7].

- **Simulation**
  Simulations are widely used in production plants to pull the real-time data to mirror the physical world in a virtual model which can include different aspects like machines, components, humans, and products [1]. Use of 2D and 3D simulation data helps to facilitate virtual testing and optimizing different aspects of the facility [1].

- **Horizontal and vertical system integration**
The paradigm of Industrie 4.0 is outlined by three dimensions of integration, horizontal integration across the entire value stream, vertical integration and network manufacturing systems and end-to-end engineering across the entire product life cycle [1]. Most of the departments in industries are not fully integrated with all systems. With the industry 4.0 departments, functions and companies become more integrated and uniform [7].

- **The Industrial Internet of Things**
The Industrial Internet of Things refers to the worldwide network of uniform and interconnected objects that communicate via standard protocols [1]. With the help of industrial internet of things, even an unfinished product can make full-fledged use of enriched embedded computing which can control their manufacturing process [7].

- **Cyber Security**
Cyber security is important or crucial for the systems in the future with respect to Industrie 4.0. Especially in smart factories, increased use of connectivity applications and communication systems increases the cyber threat for their digital systems [1]. This raises the issue for the security of these large data values from being leaked or being misused. Moreover, it requires strong and reliable cyber security for their digital world.

- **The Cloud**
Nowadays it is an essential part of companies to require more data sharing across different countries and regions. For that purpose, the cloud-based platform has been acting as the backbone for the connection and communication of an industry [1].

- **Additive Manufacturing**
Additive manufacturing is a technology from which Three-dimensional designs can be built directly with the help of a Computer Aided Design (CAD) file without the need for any part specific tools or dies [9]. The additive manufacturing technology is widely used to produce small batches of customized and flexible components which fulfill specific constructive needs that are required for instance, complex and lightweight designs [1].

- **Virtual and Augmented reality**
Virtual reality refers to a fully computerized three-dimensional environment in which user can interact and manipulate a realistic model of a product in real-time. Augmented reality is one step ahead which gives a better view of the real world with virtual objects [10].

The above sections describe the background for the need for such a concept called the Learning Factories. The base for this Literature Review is the International Conferences conducted on Learning factories over the past 3 years. The literature study is conducted with the help of papers published in the conferences using the Grounded Theory for literature review which is described in detail in the following sections. The following section describes the different application scenarios in which the Learning Factories are based.

1.2 Learning Factories

The history of implementing learning factories dates to 1994 when it was adopted across universities in order to prepare the students for the upcoming changes [11]. The 6 dimensions of the Learning Factories being Purpose, Process, Setting, Products, Didactic and Operating model [11]. The major goal of a Learning Factory can be organizational innovation (Research-oriented) or technological or as an effective tool for competency development among the personnel's and organizations. As it can be seen the Learning factories cover a wide range of environments for receiving and sharing information, the concept is divided into several scenarios based on their specific applications.

1.2.1 Industrial Application Scenario

In the industry, the role of Learning factories is commendable as they help to identify and track down the probable issues which may arise from the shop floor facility. They also play a crucial role in imparting the necessary knowledge skillset as required by the company. A significant example would be the Process Learning Factory CIP formed in 2007[11]. In the above factory, participants are provided with the opportunity to discover Lean principles and help to apply them directly onto a real production environment. The learning factories can thus be regarded as support for any industry looking for effective training for their employees at diufferent levels to meet the future needs.

1.2.2 Academic Application Scenario

The use of learning factories in the academic scenario is an effective way to make the future generation of engineers equipped with the skills that are needed in the future. The opportunity to experience a real production environment during the academic stage can be a way to their success in the industry as they move on. TU Wien in 2013 successfully integrated key aspects of “human-centered cyber-physical production systems” into the learning factory. This was meant to tackle the needs for the upcoming changes that are expected with Industrie 4.0[11].

1.2.3 Remote Learning Scenario

The Teaching factory is a concept developed to integrate the concepts of education, research, and innovation. It has emerged as an effective method for integrating a factory environment with the classroom. In remote learning scenario, communication and interaction of remotely located engineers at different areas who work on real-life academic or industrial sites are enabled. It operates in both ways. Two-way communication takes place between factory to classroom and lab to the factory. For example, with several available software, a person in United states can access a system that is placed in India for instance. This helps to provide an actual factory experience or problem encountered in any factory which is part of the network. Moreover, this can be presented to the students on which they can study and improve their skill set. It is different from the academic scenario in a way that this scenario provides a real-time interaction between the actual factory operations and users from an academic perspective.

1.2.4 Changeability Research Scenario

This scenario focuses on training regarding the transformable production platform which is specially designed for modules that can be adapted to the change of the system layout and its functionality [11]. This learning scenario targets products design, customization, and personalization [11]. An example of this scenario is an integrated systems-oriented type of learning factories which was set up at Intelligent Manufacturing Systems Center at the University of Windsor. This was the first of its kind iFactory in North America. These systems focus on integrating product design, customization, and personalization.

1.2.5 Consultancy Application Scenario

This scenario can be regarded to be in a way to be very similar to the industrial application and academic scenario. The idea is to provide the service of learning factories to the companies and institutions in need across several places across the world [11].

1.2.6 Demonstration Scenario

This scenario is based on the idea of a demonstration of the concept of Learning factories, and its use for presenting the future production and fundamental ideas [11]. A single day event could be designed so that non-industrial stakeholders could be given a basic understanding of what happens within the factory and the various interactions between the several types of equipment. This is hence an effective way to impart basic knowledge to people less involved in the process directly but still get a fair idea on what is being carried out on the production floor.

1.3 Research Questions

The above sections describes the need for an effective method to be implemented for the Learning and training process across the different application scenarios in the advent of the process of transformation to Industrie 4.0. This leads to the necessity for conducting a preliminary study based on the Learning Factories, which includes the data collection and analysis based on studies conducted and presented on the Conferences of Learning factories over the years. The following research questions have been formulated to capture the core areas under consideration here.

1. What is the role of Learning factories in training a workforce capable of handling the new technology?
2. What are the advantages of Learning Factories over traditional training techniques?

1.4 Purpose and Goal

The purpose of the master thesis is to conduct a preliminary study on the concept of Learning Factories and study its implications and the relevant process required for transformation into a state of the art training module well equipped to meet the challenges of Industrie 4.0.

1.5 Research Limitations

- The research is limited to International Conferences on Learning Factories conducted through the period 2015 to 2017
- There was accessibility issues in attaining the conference papers held before 2015

2

Methodology

In the following sections, the methodology followed to conduct the study is looked into in detail describing each section of the process.

2.1 Identification of Keywords

The scope and research questions discussed lead to the formation of the major keywords that are used for the searching of the relevant literature as required for the study. As discussed earlier, we have seen the importance and need of Learning Factories in the current scenario where all companies are striving towards a transformation into the Industrie 4.0. The major areas of importance as such are therefore Learning Factories, Industrie 4.0, Smart Factories, Assembly systems and Cyber-Physical Production Systems (CPPS). The key words are used for the searching process conducted through popular search engines Scopus and Google Scholar. The complete list of all the conference proceedings for the past three years was procured from Science Direct.

2.2 Review Method

The thesis is carried out using a specific method as required for the rigorous review of the articles. There are several methods that could be followed to conduct the review in an effective and efficient manner out of which a suitable one is selected. The paper will concentrate on the Grounded Theory as a method for effective search and analysis of the articles as stated in the International Conferences of Learning Factories. The Grounded Theory is a literature review method which includes a Five stage process for the rigorous review of the articles. The stages are namely, Define, Search, Select, Analyze and Present. Figure 2.1 illustrates the stages in Grounded theory as explained.

Each of the above stages is as explained as follows,

- **Define**
  This stage involves the identification of the most suitable data. The background, scope and the need for the selected research topic are studied and the necessary roots for the capture of literature are identified and executed. This step also includes identifying the appropriate fields of research to be included in the study along with coming up with relevant research questions. The research

Number	*Task*
1. DEFINE	
1.1	Define the criteria for inclusion/exclusion
1.2	Identify the fields of research
1.3	Determine the appropriate sources
1.4	Decide on the specific search terms
2. SEARCH	
2.1	Search
3. SELECT	
3.1	Refine the sample
4. ANALYZE	
4.1	Open coding
4.2	Axial coding
4.3	Selective coding
5. PRESENT	
5.1	Represent and structure the content
5.2	Structure the article

Figure 2.1: Five stage grounded-theory method for reviewing the literature in an area [12]

questions are formulated and projected based on the background, followed by finding the keywords required for the search as explained in the next stage. According to Wolfswinkel, Furtmueller and Wilderom [12], it is suggested that a logbook is maintained which includes all the crucial decisions and steps involved in the process. This will seem to be very effective towards the final stages of the study. The major steps involved in this stage are defining the criterion for inclusion and Identification of the field of research.

- **Search**
  This is the stage at which the actual search for the articles and relevant proceedings will be commenced. The topic and study are considered as a base for the search of the articles. The major source for the proceedings is from Scopus, Web of Science and Google Scholar. The search is carried out with the help of keywords formulated with the help of the research questions. It is possible for effective iteration in this process with the Define stage due to possible issues that may arise in the process of searching. An important process during this stage is the documentation of the search and search items, which can prove to be very effective in the review process.

- **Select**
  This is the third stage of the process and includes the process of reviewing and sampling the collected articles. The set of articles are refined, and duplicates are identified and rectified. This stage will ensure that the set of articles are ready for the final stages and well documented. This activity is mainly carried

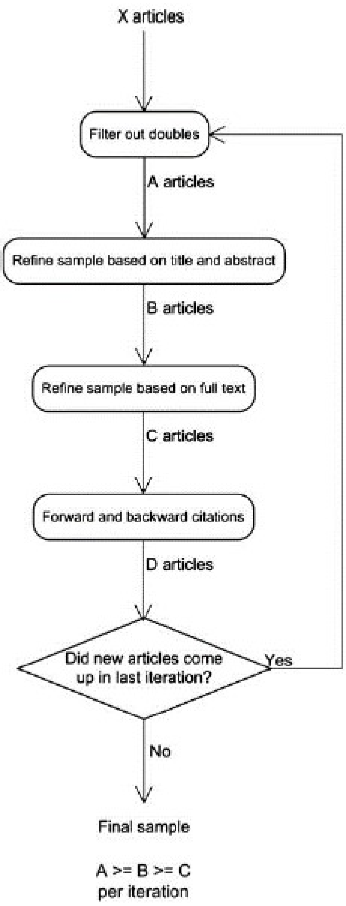

Figure 2.2: Stages in Reviewing the literature [12]

out by reading the abstracts of the articles or more so that the essence and intention of the paper are captured. The articles are usually sorted based on several relevant criteria such as year, the number of the citation with respect to the year of publication etc. This stage lays the necessary groundwork required for the actual analysis of the articles to be followed in the following stages. This stage is more precisely explained in the following diagram.

- **Analyze**
  This is the stage of the literature where the actual key principles of the grounded theory are applied to the carefully selected group of articles. This stage is responsible to extract the genuine values from the selected articles. The process is to read all the articles carefully and to highlight the relevant information in alignment to the scope and research questions of the literature review. These highlighted words or paragraphs will represent a relevant 'excerpt' [12]. These excerpts are stacked into sets and will further form a set of concepts and insights. This stage, in addition to staging results on an account of what is empirically found, also leads to possible explanations of the findings and its relevance to be accepted for the sake of theorizing.

- **Present**
  This is the last and final stage of the study and is responsible for the precise and coherent presentation of the findings which includes the concepts and insights. It also includes key decisions made during the review process. The reader of the paper expects to get a solid presentation of the findings and an overview of the concepts and insights of the review. Creativity of data is entertained over creativity of the reviewer during the structuring of the presentation.

3
Findings

This chapter deals with the findings from the review carried out based on the Learning Factories . The methodology as explained in the above section used for the Literature Review is grounded theory. The chapter explains in detail on how the literature review was conducted and analyzed using Grounded Theory.

3.1 Findings

The following section describes the actual process of the review

3.1.1 Stage 1 : Define and Search

The stages for the process of finding articles are to be carried out in an iterative format which includes going back to a previous stage if required. The value of the review enhances by better legitimization of every choice made during the review process [12]. The search is conducted with the keywords selected based on the thesis background and the keywords used are Industrie 4.0, CPS (Cyber-Physical Systems) and learning factories. The number of articles found after the search is tabulated to get an overview which makes it easier to track and sort them into the different respective fields. The searching process was mainly carried out with the help of search engine and databases like Google Scholar, Science Direct and Chalmers library. The following table displays the total number of papers belonging to respective categories.

Table 3.1: Classification of Articles

Type	Number of Articles
7th Conference	49
6th Conference	43
5th Conference	27
Others	7
Total	126

The articles are to be sorted into different fields and classified based on the year of publications, location and the scenarios on which the Learning factories are based upon.

The total of 126 articles have been sorted based on the different subcategories and tabulated. As discussed in the above sections, the major number of articles were found from the Database Science Direct with the help of the search engine Google Scholar. All the proceeding from the International Conferences of Learning Factories, 5th,6th, and 7th are taken from Science Direct and comes to a total of 115 papers. Another major source of searching is the Chalmers Library through which several additional articles relevant to the topic is taken. The next step in the process involves sorting these articles with respect to year of publication. The articles are also sorted based on the scenarios of the learning factories as well as the locations from where they are based on.

3.1.2 Stage 2 : Select

The articles are listed and sorted based on Scenarios of Learning Factories, Fields of their applications and locations. The formulated data is then illustrated in the most suitable and simple method to convey the information. The sorting of the articles also revealed that a few of them is not relevant to the scope of the thesis as they included information in detail on other aspects and specific to fields within Industrie 4.0. From Table 3.1, it can be seen that the number of articles has come up to to a total of 126 articles, which has been distributed based on the conferences they had been a part of.

3.1.3 Stage 3 : Analyze

All the papers were collected and sorted with respect to the keywords Industrie 4.0, CPS (Cyber-Physical System) and Learning Factory. These were the three primary keywords which are used for analyzing the purpose of the literature. As explained in the methodology, this section is responsible to extract the relevant values from the articles. The section includes an insight into a detailed description of the concepts of Learning Factories followed by brief descriptions of Industrie 4.0 and Cyber-Physical Systems.

The concept of Industrie 4.0 refers to the study of the most advanced industrial revolution to date. This is primarily due to the necessity for flexible production systems and processes capable of meeting the increasing complexity pf products, logistics and productivity [13]. This is achieved through the possible IT integration of the different levels including production and planning which also extends to customers and suppliers. This level of integration is made possible through Cyber-Physical System (CPS) and the entire process is collectively termed as “Industrie 4.0” for the past few years [13]. The concept of Industrie 4.0, thus has a significant effect on the workers and the organizations in technical innovations especially in the field of production engineering. The companies are hence facing the challenge to have the right amount of skilled labor required for the various tasks that are part of the new set of skill sets required for the transformation process. This is when the early concepts of the Learning Factories were introduced.

3.1.3.1 Definition of Scope of a Learning Factory

The term "learning factory" was coined and patented in 1994, when the National Science Foundation (NSF) in USA awarded a consortium led by the Penn State University [11]. The preliminary prototypes of the Learning Factories were primarily based on inter disciplinary hands-on senior engineering design projects. These projects have a very strong connection to the industry and worked in accordance with the requirements. These models were designed for gaining hands-on experience acquired through application of the knowledge gained at the engineering education with strong emphasis on solving real-life industrial problems. Moreover, the focus was also based on designing and redesigning products to the needs and requirements acquired through the process [11]. Over the following years the focus on the research on Learning Factories shifted to the European countries, led by Germany. In the year 2011, at the 1st Conference on Learning Factories held in Darmstadt, the concept of learning factories took a shift and emergence into the European scenario [11]. Furthermore, this ignited the much needed importance into the rise of research all over Germany and several Learning Factories being set up in different parts of the country.

As mentioned above, the shift in the location to European scenario had a direct impact on the existing Learning factories around the world. For instance, in Germany, one of the major causes for the increased research were the rising energy costs which posted a major challenge for the manufacturing activities across the country. Hence it calls for an energy efficient system to be implemented to tackle the issue [14]. Moreover, an important approach to the learning factory is to leverage industry processes and new manufacturing knowledge and technology [11]. Hence in this scenario, the scope of the Learning factory designs will be focused on the energy efficiency and sustainability of the equipment and processes. Another example was the introduction of Lean concepts into the manufacturing industry across Europe and companies striving to transform into a Lean process which is also directly linked to the energy and resource saving as required my most industries in Germany and Luxembourg. The University of Luxembourg, recently launched its Learning Factory, called the Lean Manufacturing Laboratory [38]. The companies tend to invoke the Lean concepts in to their operation as the current trend is leaning towards individualization of products due to the increased needs of the consumers [38].

3.1.3.2 Traditional Training Techniques vs Modern Training Techniques

Over the years the methods of training personnel have evolved, and it has reached a stage now when there is a requirement for a huge leap in technology and related services. Here it is been discussed about few aspects of traditional training which is very useful for the comparison with the current or present training ways with the traditional ways. As like changes that happened in these years throughout the world, identically situations changed in all part of industries. As it is seen today, training techniques and learning factories were not that futuristic in olden days.

In today's world, personnel's related to different industries might have come across different learning factories for different purposes. These all are done with the certain specification for specific tasks. Most of the engineers or industrialists might have heard the term "traditional training" but have not tried to study or analyze the difference between the old school traditional way and the modern way (which can also be called as learning factories). Traditional training is referred to a course or class offered in a physical location with respect to a particular trainer [15]. As seen today, even in the early 70's or 80's in many organizations there were separate planning, administration, and coordinating programs were conducted for employees in the organization [16]. For a long period of time, specific training for performing specific tasks and jobs were considered as the responsibility of the public sector [17]. This means that the process of training takes place outside the workplace which is entirely separated from the entire business and industry [17]. According to fiat car chairman, the gap or relative distance between the school and industry were always an issue. Due to this situation, the decisions were taken for the vocational training programs collaborating universities and industries, precisely called polytechnic a system of education people for jobs outside the schools [17]. In an organization when an adult education is undergone as a subordinate function it is referred to training [16]. This process can be undergone by an individual which can help to improve, develop individual skills for the appropriate performance of the personnel towards an organization.

One of the main difficulties faced when people are being trained for jobs is to meet the requirements of industry [17]. The requirements of the industry are directly proportional to the rapidly changing skills with respect to shifts in technological environment [18]. This was the main reason for the introduction of apprenticeship and vocational training inside the industry. Main difference which differentiates the current learning factories with the traditional training is the evolution of the training process in the traditional way [17]. Evolution of traditional training process was of different steps and they are [17].

1. **Reconstruction**
   This stage was considered in which training provided by the institutions were considered to be an effective product for the industry. But still, skill sets for the new workers were passed down by the old workers through small workshops [17].

2. **Expansion**
   In this stage, institutional training was kind of separated from the industry but sticking more on to the special skill sets [17].

3. **Crisis**
   In this theory, institutional training should not be influenced by the labor market. The industry was becoming incapable of handling or extending the quality of work. Therefore, in-house training started to get more and more consolidated [17] .

4. **Technological innovation**
   Institutions were returned back to work more closely with work and industries. Due lack of skilled labor and employment among young people [17]. In this stage, several attempts were made to align the training with the labor policies.

There were many obstacles which were faced by traditional training in that era. Even Though there were many technological up-gradation, inventions, organizational changes were ongoing the human resources was still a problem [17]. According to Frigo, Franco there were obstacles to implement developing management, technical and vocational training for already and new coming workers and that difficulties are may be due to lack of human resource planning, lack of financial resources, lack of time(it is always time is a factor for everything especially for staffs and management) and the difficulties faced by the medium and small industries for getting skilled labor due to over possession of resources by the big companies.

The main objectives which can be considered for the transformation from traditional training to modern learning factories are better knowledge sharing between the academia and industries, for the better product development processes, to make the professionals to be more competitive in their specialization [18]. The role of technological advancement in learning and training is unavoidable. Technological advancement after the third industrial revolution has given rise to modern networking and computational tools for better learning and training [3]. Especially online learning and training has put a leap forward in terms industrial education. Especially the IT revolution has brought the different senses of the human into reality, like the digitally represented forms of all information's around the world into the devices in front [20]. The different type of scenario including Academic, Industrial, Remote learning, Changeability scenario etc are the best examples of technological advancement which paved the way for different ways of training what we see today. As told earlier there is nine technological advancement which laid the foundation for Industrie 4.0. These technological advancement revolutions mainly started after the third industrial revolution [3]. This is mainly stated to show the relationship between training and technological advancement. Prior to the third industrial revolution, during the time 60's to late 80's training weren't that much of importance. As it has been discussed earlier the revolution of technological advancement changed the complete attitude towards the process of training. Many of the international organizations and multi-national companies understood the value of training and considered it as a value-adding resource.

There are several advantages of the modern learning factories over the traditional way of teaching. The main factor that makes modern learning factories differ from traditional training is the technological advancement that has been mentioned earlier. The main advantages obtained from these technological advancements are, all in-formations can be channeled under one network where it can be easily accessible for different purposes, systematic way of training with respect to these systems, all personnel are considered and equally treated if there is a systematic system, improved competency of trainers and finally gathered information can be re-evaluated

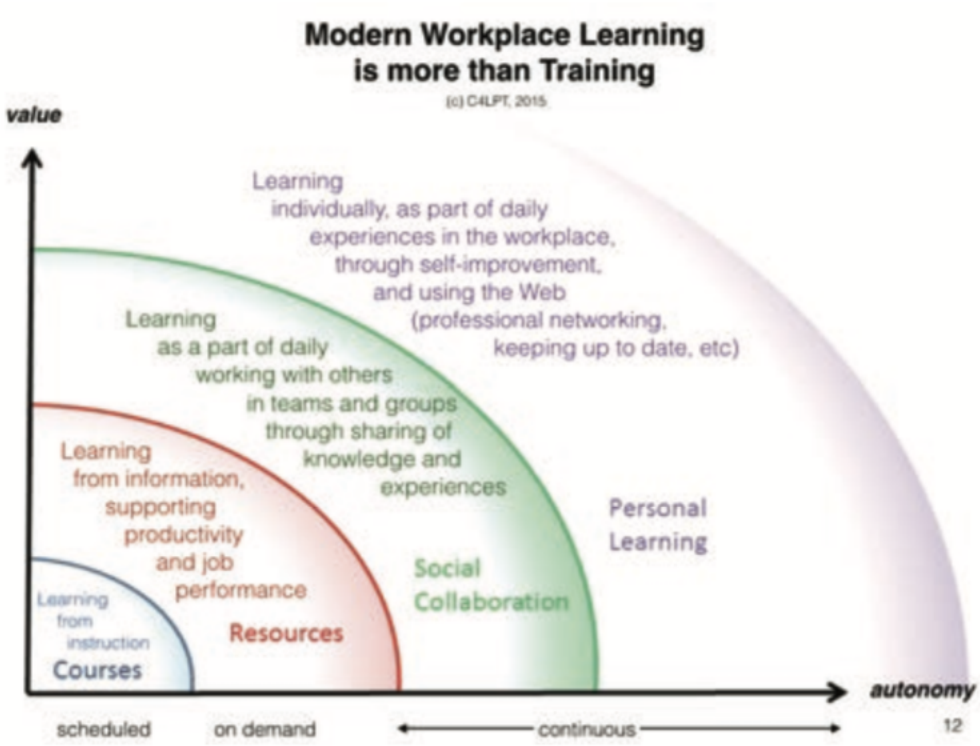

Figure 3.1: Modern workplace learning framework Layouts [23]

and updated with respect to new in formations available [17]. When it comes to business perspectives of an organization it always makes relatively cheaper operating costs. Face to face training or physical training and operating costs from this perspective was the main disadvantage of the traditional training which made it be considered as the minor role [17].

The factories of the future will be termed as smart factories with the influx of new communication and information technologies along with advanced control systems empowering automated robotic cells. As described in earlier sections these changes are currently termed as Industrie 4.0. The learning factories developed for such changes provides a realistic production environment with the help of their technical equipment [21]. This call for a need for the Learning Factories and its importance in the preparation of employees for the use of Industrie 4.0 and to be closely linked to Cyber-Physical Systems (CPS) as well [21].

According to Rentzos et al, in the 5th Conference of Learning Factories, the current practices in imparting the knowledge to the workers is deficient when it comes to a continuous delivery of engineering competencies in multidisciplinary backgrounds [22]. The authors have presented a way to tackle the above problem with the introduction of the concept called “the Teaching Factory”. This concept is built upon the knowledge triangle notion, which is expected to become a new paradigm for academic and industrial learning process [22].

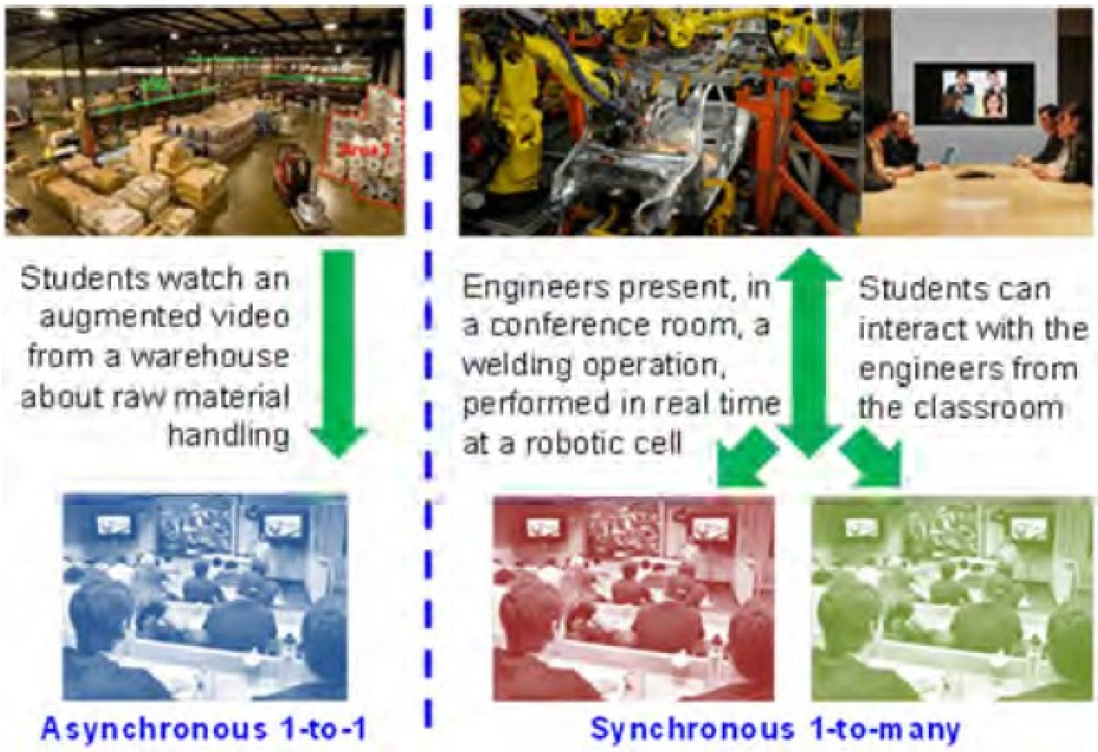

Figure 3.2: Five Different Teaching Factory Layouts [22]

Figure 3.2, represents different forms of the Teaching Factory Concept, displaying a one-to-one system and one-to-many system. The latter is capable of an interaction of the factory to several different numbers of classrooms across several locations. The paper also states two important concepts within, namely the "Factory-to-Classroom" and the "Academia-to-Industry". Moreover, it describes the flow of communication between both the factory floor and a classroom, providing interaction of both stakeholders to help each other out in solving problems. The paper describes the concepts in the form of pilot experiments conducted in a university in collaboration with a construction equipment manufacturing company. The students were given actual tasks or industrial problems and were asked to work on them. Moreover, the blue-collar workers were introduced to newer technologies and innovations that are popular in the current scenario relevant to their specific requirements [22]. In the concluding remarks of the paper it includes a concept of a business model which focuses on the bi-directional knowledge transfer through an establishes Teaching Factory Network. This is an interesting and broader application of such a concept.

The above example of the concept of a Teaching Factory gives us the Idea of Learning factory in mist of the scenarios including Academic, Industrial, Remote learning etc.

3.1.3.3 Learning Factories for Resource Efficiency

As it is seen in the above sections, the increased competition on a global scale pushes the companies to depend on trained personnel. This has led to the increased revenue

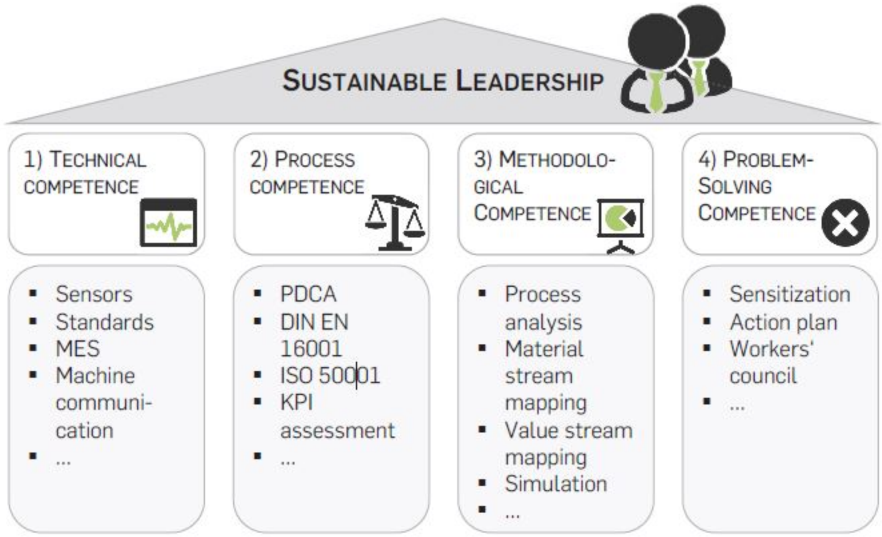

Figure 3.3: Subdivision of four competence areas in the LRE [24]

on Learning Factory research [24]. From the sorting of articles its found that Germany leads in the research on Learning Factories as from the fact of its importance in the implementation and possible transformation of the industries of the future into Industrie 4.0. In the case of Germany for example, the resource efficiency is poor and this leads to for importance for resource-efficient production processes [24]. The major focus of the Learning factory at Ruhr- University of Bochum is the design and optimization of resource-efficient production processes. Within the concept different forms of training has been developed for participants belonging to different business levels [24]. These processes are conceived with accordance to the PDCA learning cycles which in turn helps the participants to share their experiences and concepts to their own companies and processes. In order to qualify in the PDCA process, a fundamental knowledge of the different fields of competence is necessary. Figure 3.3 describes the different competence levels as expected for the Learning Factories for Resource Efficiency (LRE).

The 4 major competence levels are in the fields of Technical, Process, Methodological and Problem Solving. The application of methods of Optimization takes place in the third competency level, namely in the methodological section. Here, the participants first analyze the manufacturing process, so that they can gain a quick overview of the implications of the process. This followed by a conversation with the operator of the learning factory (LRE), the aim and goals of the company can be passed on emphasizing the need for resource efficiency [24]. The participants then analyze and measure energy consumption along with other relevant information such as Process times, the number of employees and material and information flow. This is carried out with the help of various software tools which greatly simplifies the process. These parameters are then analyzed and tabulated. This is followed by the process to find the main resource drivers, which in turn helps to rate and benchmark the process on the basis of the collected information [24]. Finally, a holistic assessment and investigation of the input and output of the production process are carried out

Figure 3.4: Data collection with the Manufacturing Execution System in the LRE [24]

with the help of the material stream mapping method [25].

During the training process, the teacher makes use of the dual energy signature. It is a specification of the normal value stream mapping [24]. The processing time then split into a value adding and non-value adding process. This can be practically presented during the training process. The times, for example, are captured as follows, the value adding time is captured when the machine tool is executing a workpiece and non-value adding time is captured when the machine tool is not executing a piece. The difference in the collected data gives the value-adding usage of energy. This is then used to modify the value stream with the distribution of energy. This is followed by the whole value stream mapping for both the main processes such as sawing, milling, lathing etc and the peripheral processes such as ventilation, lighting, heating etc. Hence every aspect of the used energy is analyzed so as to optimize the consumption [24].

Furthermore, based on the study and data collection that had taken place in the above steps, it is followed by a resource-driven Sankey analysis [26]. This is used to capture resource efficiency within the process under consideration. Therefore, the production process is represented in a simplified way and the optimization potential is derived in the seminars visually[24]. Additionally, with help of sensors, the possibility of direct evaluation using the Manufacturing Execution System (MES) is attained. The Manufacturing Execution System (MES) of the Learning Factory saves all the measured data, which can be accessed for evaluation and planning [24]. The benefit of such a system is that the data can be even accessed with the help of remote controlling devices. Figure 3.4 shows an example of an image which depicts the data collection and presentation with the Manufacturing Execution System (MES).

Thus it can be seen that the process of resource optimization is essential when it

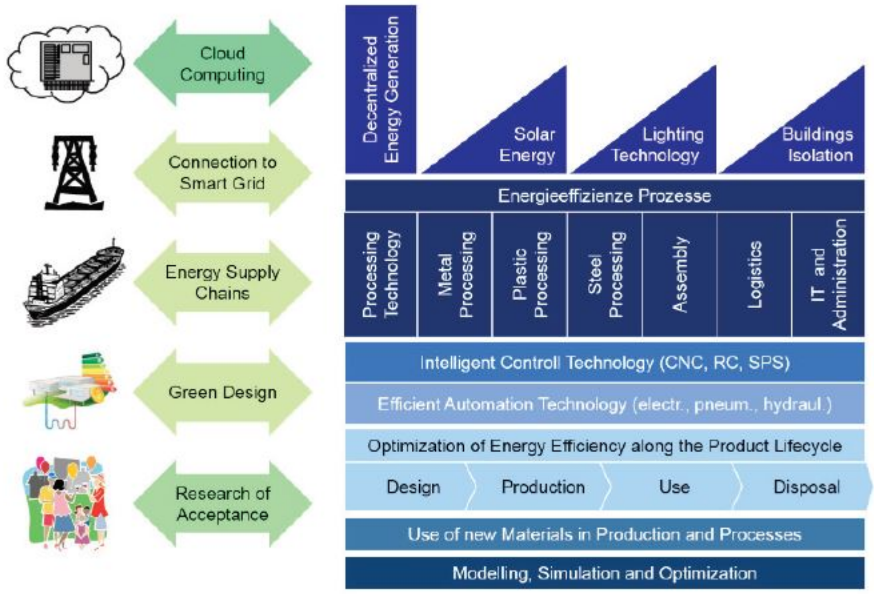

Figure 3.5: Research priorities and cross-cutting issues of the Green Factories [27].

comes to the development of a learning factory, especially considering the case of countries having poor resource efficiency. This leads to the need to conserve energy to increase productivity and hence make revenue.

Another notable resource-oriented approach to Learning Factories is yet again in Germany. The factors that led to such an initiative in Bavaria was Germany's exit from nuclear power [27]. This also forced Germany to concentrate on more energy efficient processes especially in the field of Manufacturing. The Green Factory Project enhances the capability of Bavarian companies in improving their resource competitiveness. Figure 3.5 depicts the research priorities and cost-cutting issues of the green Factories.

3.1.3.4 The Fourth Industrial Revolution

The development of smart factories is an important aspect of the transformation of industries all over the world [28]. The new trend of industrialization is going all over the world; therefore, all nations are dumping enough and more funds for this development [28]. In each region, this new revolution of the industry is called in different names. For example, in Sweden it is called "smart industry", in Germany its "Industrie 4.0", in India its "Make in India", in the U.S its "advance manufacturing" etc. The four main drivers of the Industrie 4.0 are namely, Internet of Things (IoT), Industrial Internet of Things (IIoT), cloud-based manufacturing and smart manufacturing. Even though it has different names it is all part of the new industrial revolution. Main difficulties in implementing Industrie 4.0 are high investment costs and in high qualification requirement [29]. Since the concepts of Industrie 4.0 tremendous drivers for IT enriched production systems are becoming more complex

Sr.no.	Name of Robot	Company	Function of Robot
1	Kuka LBR iiwa	Kuka	Lightweight robot for sensitive industrial tasks
2	Baxter	Rethink Robotics	Interactive production robot for packaging purpose
3	BioRob Arm	Bionic robotics	Use in close proximity with humans
4	Roberta	Gomtec	6-Axis industrial robot used for flexible and efficient automation

Figure 3.6: Autonomous robots used in different industries [31]

in their structure and functionality [29]. Presently most of the organizations try to integrate systems which are connected to value-added processes like product lifecycle management (PLM), enterprise resource planning (ERP) which are required to track all details what is happening in production [29].

Nine Pillars of Technological Advancements

As mentioned several times in the report the core objective of the Fourth Industrial Revolution is the fulfillment of individualistic customer needs, which in turn affects areas such as Order management, Research, and Development, delivery to utilization, recycling etc. The Nine Pillars of Industrie 4.0 can be summarized as follows,

- **Big Data and Analytics**
  Big data and its analysis constitute the process of collection and a comprehensive evaluation of data from several sources working in accordance with the various systems used in the industry such as the Enterprise and Customer Management systems (ERP software). This in effect supports real-time decision making [1]. According to Forrester, the definition of Big Data consists of four dimensions, which are Volume of Data, Variety of Data, Velocity of Generation of new data and analysis and Value of Data [30]. The analysis of the data recorded in the past help to learn and study the threats and issues that have occurred in the systems which are then tabulated and tracked. This process also becomes essential when it comes to solving and identifying issues that may arise in the future. Hence this can be taken to be an effective error management and a concept for enhancing the working of the system.

- **Autonomous Robots**
  Robots are currently becoming highly autonomous and are at a rapid rate learning and developing at the same time. This is through the fact that they are highly flexible and cooperative, which means they are capable of working side by side among themselves and also in the process learn from humans. Robots are capable and are so designed that they can outperform humans in several areas and also work in environments otherwise hazardous for humans to work. For example - robot manufacturers like KUKA and ABB manufacture autonomous robots with sensors which can interact with humans for more safety [1]. Figure 3.6, shows a table which depicts autonomous robots used in a few industries.

- **Simulation**
As it is mentioned in the above sections, one of the major concerns of the industry is to reduce waste accumulation. Simulations are widely used in the industry today to leverage or make use of real-time data and hence arrive at a place where the physical world is mirrored in a visualized or virtual model. Use of this data can also help to reduce the setup time when they set up the machine for the next product. Moreover, the overall decision-making quality can be improved swiftly with the help of simulations [1]. The model can include from machines and products to humans which is part of the scenario. Such a model can help to greatly reduce the machine setup times and have a positive effect on the Quality of the products manufactured. Multidimensional images and models can be developed with the help of simulations which can be utilized for Virtual Commissioning of equipment, improving the ergonomic aspects of the facility, controlled energy consumption, and simulation of cycle times. These techniques can greatly decrease the machine down times and help to control production failures hence improving the overall quality of the production facility.

- **System Integration: Horizontal and Vertical System Integration**
Industries today need to focus on working together as a unified and integrated system. This is where the role of System Integration comes into the picture. Integration and Self- Optimization are the two major mechanisms that are followed by most industrial organizations across the globe who are striving for maximum productivity [1]. Figure 3.7 shows the three types of System Integration. the paradigm of Industrie 4.0 mentions the types of integration as,
    1. Horizontal Integration across entire value creation network [1].
    2. Vertical Integration and network manufacturing Systems [1].
    3. End-to-end engineering which expands over the entire life cycle of the product [1].

  Horizontal integration and vertical integration refers to the operation strategy of the organization (including all policies and aspects) which are setup to enhance their performance and efficiency.

- **The Industrial Internet of Things**
The internet is a system of interconnected devices through a network capable learning and sharing information among each other. The Internet of things is a worldwide network which is a system on uniformly addressed objects which communicates with each other via a standard protocol. The Internet of Things (IoT) others wise also called the Internet of Everything (IoE) contains the concepts of the Internet of Services (IoS), Internet of Manufacturing Services (IMS), Internet of People (IoP) and embedded systems and Integration of Information and Communication Technology (IICT). The key features of IoT include Context and Omnipresence. It deals with the object interaction with the environment and responds to immediate changes that may occur in the system. This field allows communicating within the different machines and

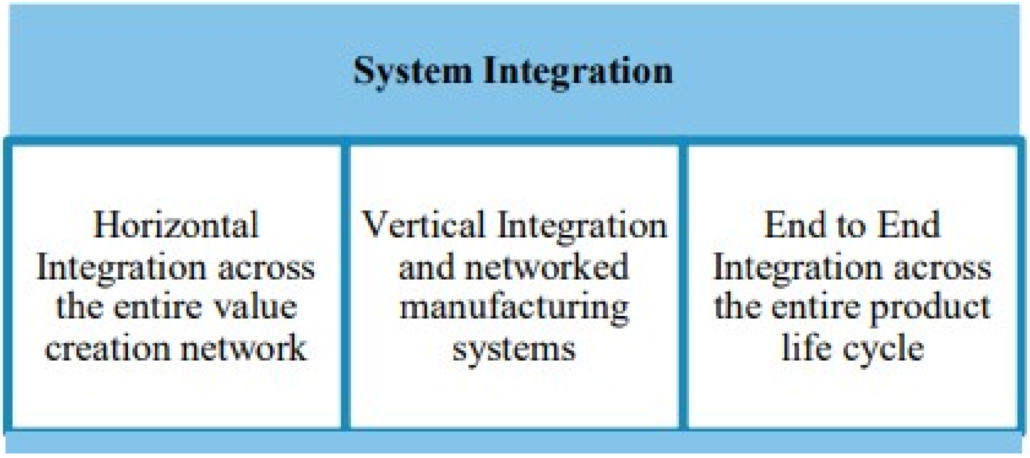

Figure 3.7: System Integration [1]

devices for process controls within the system with strong requirements such as continuous operations, safety, real-time operation etc [8]. The value chain is expected to be agile, intelligent and also connected by integrating physical objects and human factors, including intelligent machines, smart sensors, and various production procedures across the organization. The combination of software and data leads to intelligent planning and control of machines and are hence the key elements of the concept.

- **Cyber security and Cyber Physical Systems (CPS)**
  With the increased connectivity and networking along with the standard communication protocols, can exponentially increase the chance of security violations and threats to the critical industrial systems and assembly lines. As a result, more secure, reliable and better access management of the machines is to be achieved. Such a situation cannot be accepted under any circumstances. The evolution of Cyber-Physical Systems forms a major part in the process. The concepts behind Cyber-Physical systems have been explained in detail in the following sections.

- **The Cloud**
  The concept of cloud computing in IT refers to the connection and communication of the major manifold elements of the main Application Center of Industrie 4.0. Hence it can be called as the technical backbone of the system. Within the cloud-based data sharing all kind, data sharing has been deployed to cloud-enabling more data-oriented services for digital production systems. Finally, the systems that control processes may be operated [1]. This provides a facility for increased data transfer and knowledge across several platforms and companies with almost instant time expense.

- **Additive Manufacturing**
  Additive Manufacturing provides a means for construction of complex lightweight designs and has construction advantages. The increasing individual-

ization of goods and reduced time to market them are major challenges faced by several companies. We can overcome these issues with the help of additive manufacturing techniques. The use of additive manufacturing helps to reduce transport distances and stock on hand. The production process is faster with the introduction of technologies such as Fused Deposition Method (FDM), Selective Laser Melting (SLM), Selective Laser Sintering (SLS). The decreased product life cycle and increased customization of the products lead to increased complexity in the organization and the processes involved.

- **Augmented Reality**
  Augmented Reality Systems refers to a wide variety of support services capable of enhancing the process in the facility. The application of such systems varies over operations for example from selecting apart from the warehouse to sending repair instructions over network devices over long distances. Hence aids the process of integrating the operations of factories across several parts of the world by sharing and transfer of knowledge among each other. Augmented reality systems support different services and provide workers with real-time information to improve decision making and work procedures. Services like sending repair instructions according to the spare parts in inventory and showing the real-time instructions in devices like augmented reality glasses, for repairing specific parts which needs to be repaired. These kinds of services are continuously improving over for the last few years [1].

3.1.3.5 Cyber Physical Production Systems

Cyber-Physical Systems (CPS), plays a very important role in terms of production and manufacturing system. This is mainly because the future market and manufacturing system like Industrie 4.0 requires an adaptable system for manufacturing and production systems [32]. Interconnecting, automation and optimizing of different processes of production can lead to better handling of the future needs of the manufacturing and production industries [32]. This can only be done by a decentralized controlled network of CPS. The development of this kind of decentralized system paves the way for new services and systems which enhances the standard of industrial society. CPS (Cyber-physical system) presents the study of the decentralized controlled Cyber-physical system in a production system. Cyber-physical system is a system in which different computational elements are associated to control physical systems [33]. Some of the basic examples of decentralized CPS are production line in a manufacturing company, WSN (wireless sensor networks), power grid, usage of CPS in water supply system, traffic control and transportation system [33]. All the above mentioned so far called examples of CPS its mainly because all the controls of all components in each system are fully distributed and eliminate the need for the centralized controlling system [33].

When the different components in the system are not interconnected to each other it is said that it is controlled by a central device. But with the help of CPS, these devices are decentralized which decreases the complex nature of the system and also helps in increasing responsiveness and versatility. This decentralization

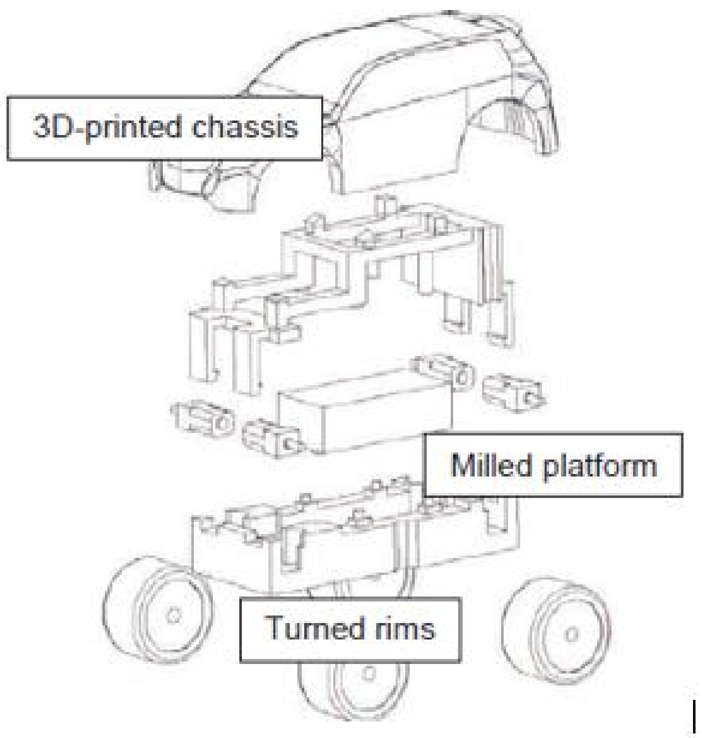

Figure 3.8: Demonstrator of the learning factory [6]

process is done by adding single board computers for each component in the system so that we can have access to status and real-time information of each and every component in the production system. Cyber-physical production system (CPPS) consists of interconnecting, combined Cyber-physical production devices (CPPD) [6]. CPPD are the components of the system which are mentioned above. The most important feature of CPPS is a bridge to computation services among CPPS itself [6]. Connection with these services helps to access information from different services like ERP and MES. With the help of these interconnectivity CPS can obtain detailed information on their given tasks [6]. Therefore, CPPS is capable of taking decisions and executing them [6]. One of the examples will be discussed here to a better understanding of the Cyber-physical production systemm.

For this purpose, one section of remote control car production is demonstrated. The main parts of this car can be divided into four and they are an additive manufactured chassis, a milled car platform, turned rims and some additional parts [6]. Figure 3.8 depicts a model as developed as per above process of complex manufacturing system based on the Learning Factory concept.
Here, it is only discussed about one area among the several and the task is to execute orders automatically for the mentioned parts above [6]. Since this system which we are discussing is a decentralized system, therefore, each device in the system collects information of orders from the internet database. Each device in the system is connected to single board computers with two ongoing programs running. In which one of the programs controls the application and the other program controls commu-

Fraunhofer Layer Model of Industrie 4.0 Value Creation: Production layer				
Engineering	Manufacturing Technology and Operations Mgt.	Machinery and Facilities	Smartification	Robotics and Human-Robot Collaboration
• Virtual commissioning	• 3D printing	• OPC UA	• Auto-ID	• Mobile robotics
Production Planning and Control	Logistics	Work Organization	Resource Efficiency	Workplace Design and Work Assistance Systems
• Paperless production	• Material flow simulation	• Agile development	• Energy monitoring	• Augmented and virtual reality • Pictogram-based assembly instructions

Figure 3.9: Industrie 4.0 classification and related topics in the learning factory [35]

nication. The application program is the program which controls the applications like movements of the different robots or devices in the system. And the communication program controls the communication between the different devices in the system. This system is an example for Cyber-Physical Production System (CPPS). Similarly, demonstration factory in RWTH Aachen illustrates complete production processes which set a good example for CPPS learning factory [6].

With the help of decentralized CPS with the IOT (Internet of Things) has many possibilities to tackle the arising challenges within the adaptable production system of Industrie 4.0. Some of the notable challenges for the production or manufacturing companies today are volatile nature of market, complex nature of variants due to competition and decreased product life cycle [35]. Therefore, as mentioned earlier, to tackle these challenges CPS is a really important step for developing smart production system [35]. In order to adapt these technologies for the smart manufacturing, highly qualified and competent employees are required. In order to meet this requirement, the proper way of training and knowledge sharing should be provided for the employees. Learning factory for CPS includes different methods and technologies from Industrie 4.0. Figure 3.9 depicts the classification and related topics and is based on the classification of 'Fraunhofer layer model of Industrie 4.0 value creation'. Each element is shown in the table there are learning activities going on in the learning factory. This system has been practicing in green factory Bavaria which is located at Augsburg, Germany [35].

Main targets of this learning factory can be divided into two and they are industry and academic. Further industry category can be divided into providers and users of Cyber-physical production system [35]. Providers will be top-level engineers or managers who want to implement the latest system for their best results and users will be the engineers and employees who work the system for the industry. When it comes to academic it mentions students who are going to be the future engineers or driving force of the system and it also helps them to achieve extra knowledge other than the normal lectures from the colleges [35].

3.1.4 Stage 4 : Present

The final stage in the Grounded theory process is the present stage, in which the data selected and analyzed is illustrated in the form where the information can be conveyed to the reader along with the thoughts and findings of the research. This stage also forms a platforms where relevant data analyzed through research from the articles are displayed and discussed so as to bring out the possible results of the thesis. Graphical representations of various forms are used in the thesis for the above purpose. The following chapter elaborates on this stage in detail.

4

Results and Discussion

The following section describes the formulated results and discussions based on the review and presentation in the form of graphical illustrations.

4.1 Compiled Results

From the above sections on the Learning Factories and their applications, it can be seen that, there is an increase in the amount of research being carried out in several parts of the world in the field of Education and training based on the concept of Learning Factories. Since the major scope of this thesis is confined to the International Conferences on learning factories the articles can be found and tabulated based on several criteria. It is quite noteworthy to see how the concepts of Learning factories are being developed in several different sites across the world. This study provides the reader with a perspective view on the possible development trend and existing research progress in the field of Learning Factories. As well their intentions in the transformation to the Industrie 4.0. The above representation also throws into light the different locations where potential development in the field is expected and also to be improved over the coming span of years. The graphical illustrations tend to provide a simpler way to see the data and be able to interpret it into coming to discussions and conclusions.

From the analysis part of the study, the path of the trend of development and evolution of the concept of learning factories can be identified along with the importance of related sections on Cyber-Physical Systems, Industrie 4.0 etc. over the years. The shift in the pattern of the existing techniques over the traditional or the conventional forms of training is commendable and also a necessity when it comes to the requirements as expected to be in the future of the manufacturing industry. Moreover, it is also important to look into the different types and scenarios of learning factories and their advantages and effectiveness within the industry. This can be interpreted from the data collected and combining it with the different geographical locations where it is researched over the time. The locations where the research is being carried out has significant implications from the society it is based upon. For example, in Germany, as we can see from the data in Figuure 4.2 has the most number of research activities outnumbering every other country. This is due to the nature of the countries policy into adapting to the new technology which is understandable as the concept of Industrie 4.0 was first introduced in Germany. Therefore, the above information shows the significant effect of Industrie 4.0 into the development

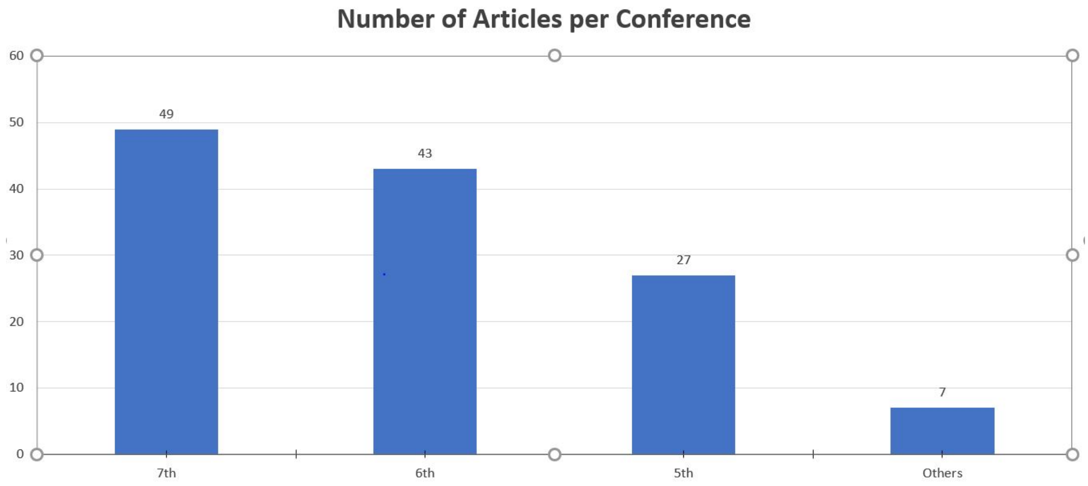

Figure 4.1: Number of Articles per Conference

of Learning factories. This is the trend that needs to be carried out to the other areas for their respective transformation into the Fourth Industrial Revolution.

The list of articles is sorted based on several criteria, for the simplicity of the presentation. Figure 4.1 shows an illustration of the number of articles per conferences held. From the data, it can be seen that there is a gradual increase in the number of articles presented over the years. From the graph and data attained it is understood that there is an increased urgency to impart the knowledge base to the stakeholders.

The extent of the research can be tracked and analyzed by grouping the papers according to the areas where the research was conducted and also into the different scenarios in which we find the applications of Learning Factories. It can be read from the graphs that in the current scenario a major portion of the research in the area is concentrated around Germany, where as mentioned earlier, the concept of Industrie 4.0 was introduced. This is illustrated in Figure 4.2. Furthermore, it is also interesting to note that a major share of the research is being carried out in the fields of Academic and Industrial scenarios with respect to others.

Furthermore, the articles are also sorted based on the different scenarios they are based upon. As discussed in the above chapters, it can be seen that the most common scenarios on the Learning factories are the Academic and Industrial scenarios. Several Learning Factories around the world which operates currently can be included in either one of the above scenarios. This can be evidently seen from fact that a majority of the articles are focused on these scenarios namely are Academic and Industrial. This has been illustrated in Figure 4.3.

The analysis of the articles is an effective way, as mentioned above in Chapter three, in understanding the evolution of the research on Learning Factories across the world. Figure 4.4, represents a consolidated representation of the data that has been formulated. It shows the distribution and trend of the Learning Factory research per Location and scenarios.

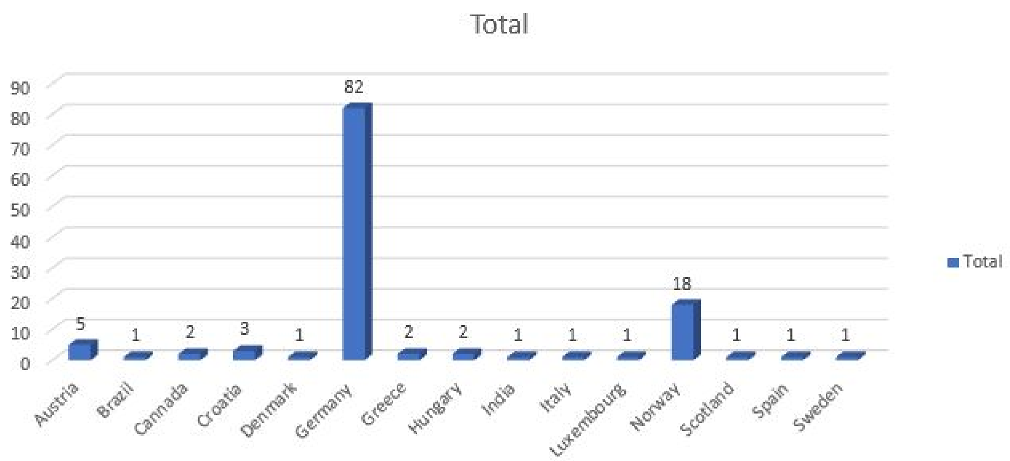

Figure 4.2: Number of Articles per Location

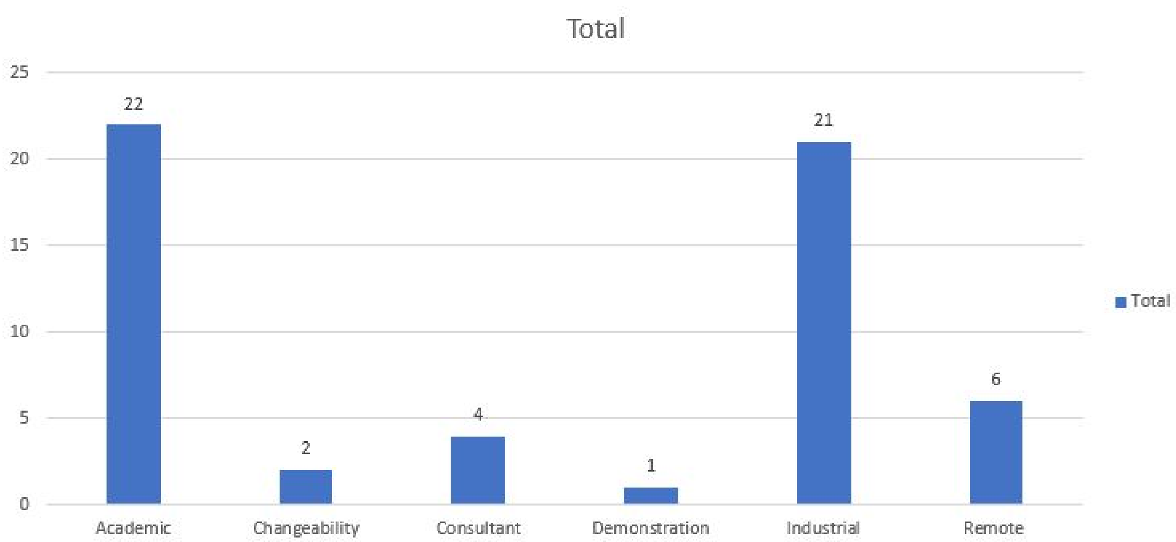

Figure 4.3: Number of Articles per Scenario

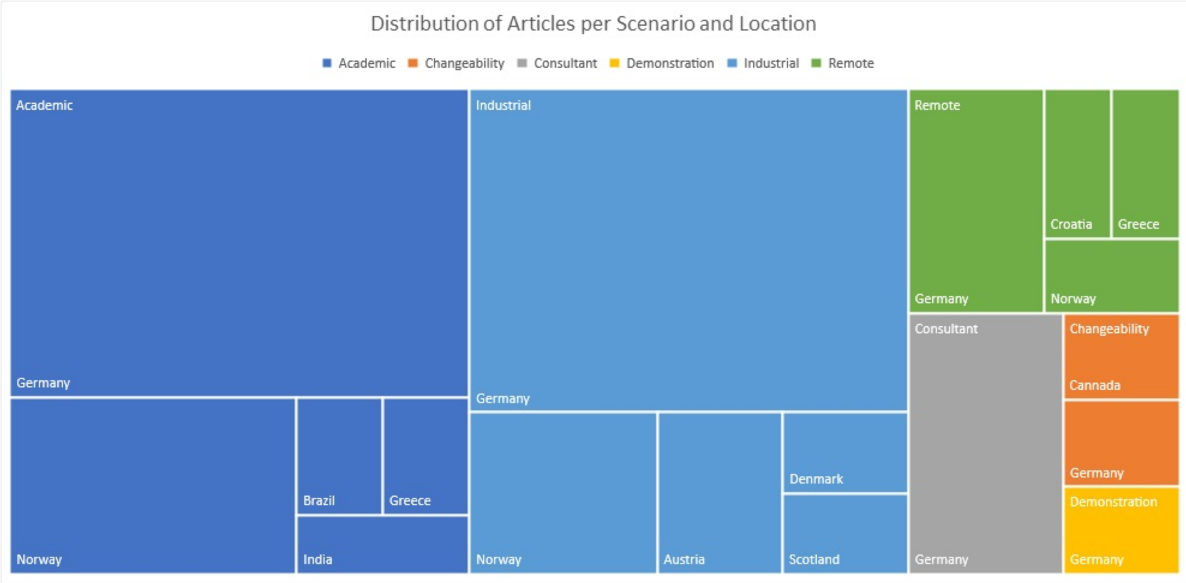

Figure 4.4: Number of Articles per Location and Scenario

From Figure 4.2 and Figure 4.4, it could be seen that researches are mainly concentrated in some part of the world, especially Germany and Norway. Since the technologies are developing day by day. It's been always a chance for new opportunities and possibilities when considering the whole world as the international market. As it's been discussed about Industrie 4.0, the revolution of smart factories are all over the world but still from the data and charts available its clear that training and learning aspects of the new industrial revolution is not that diversified all over the world. There might be a large number of big and small organizations all over the world who are still not a part of any industrial revolution or still not aware of technological advancement and the new industrial revolution.

Training is always an important factor when considering industrial and academic aspects. Training is one of the key aspects to attain knowledge and skill regarding any topic. If an individual or personnel just by having vast subject knowledge does not mean that he has the right practical skills that are required. Therefore training can be considered as a key to attain and share knowledge and finally using it in a healthy way. As per the data, it could be seen that learning factories are more concentrated only in some regions and it does not seem to be a healthy knowledge sharing throughout the world. With the help of revolutionary advancement in ICT based systems, knowledge sharing among the industries and institutions are not a big deal. As discussed about different aspects of Industrie 4.0 and associated fields, these aspects include how modern learning are used and utilized. Still, in most parts of the world, this revolution has not made any changes. Market shifts and industrial changes have been happening for a few years and the main examples are the emerging production market of Asia and Latin American countries.

But from the data collected, it can be seen that the studies carried out regarding learning factories and associated areas in that location are pretty much less when compared with the major countries plotted in the data. For that purpose sharing of information based on ICT should be promoted. Different pillars of the new industrial revolution, as well as their advantages and uses, should be reached to all parts of the world. Lack of studies conducted in this particular area can be one of the reasons for less awareness and information about technological advancement. Therefore without many studies regarding the training aspects in the upcoming market locations it is very difficult to bring all information under a system for future developments. All the actions can only be done if there is a proper channeled system for data sharing between all industries and organizations in the world. For this purpose, an association or consortium can be formed in which several organizations can be joined. This type of association can be organized in different levels like local, national and international levels. The main purpose of this association is to set up a private law for the welfare of members in that particular association so that they could help each other in different ways. For example, data and information sharing regarding new technologies etc. This kind of system can be set as a good example of healthy knowledge sharing with integration of all kind of new technologies.

As it is been known, there are different industrial revolutions through which world has passed through. Each industrial had its own importance. The area where we concentrate mostly is training and associated fields. Training was one of the notable improvement in the third industrial revolution. As per the studies, prior to 90's the term "learning factories" was only a concept and the term used was just "academic" or "industrial training". From the beginning to the mid of third revolution it was mainly about the aspects of traditional training. Followed in 90's the introduction of learning factories and technological advancement in all aspects of industries was a remarkable point. The introduction of management and organization policies regarding training was also the part of third industrial revolution. But as per the study, the concept of learning factory was only introduced in 1994 and before that training was considered as less resourceful and it was mainly due to cost issues. But later by the mid of third revolution, there have been drastic changes in terms of training in and out of the organizations. This all was in the case of a big organization. As like today, in small and medium industries they had issues with training. But in early 60's to late 80's industries was mainly dependant on the traditional way of teaching and learning.

In several organization, the recruitment of apprentice and young people are done but when it comes to small and medium organizations the role of training for this newcomers doesn't go that long as it is been required. In 60's training was considered as the public responsibility which is carried outside the industry. This was mainly due to the financial factor which considers training as an extra burden. After that in-house training as well as the collaboration between institutions and organizations were introduced. But still, with the traditional training, it was a long way to go for small and medium industries to be a part a system. The main reason for this situation is due to the lack of technological advancement and a dedicated training department at that time. Traditional technique was mainly based on the instruction given by an instructor at a physical platform. When considering financial factors to

Figure 4.5: McKinsey Learning Factory Network [11]

accommodate this system, small and medium organizations feel the training to be inadequate and a waste of their resources. This was mainly due to lack of facilities at that time

The research for thesis was carried out within a limited number of international conferences conducted over the past three years. The main subject used for study is modern learning factories and for the better understanding of the research questions, the above section discusses briefly the scope of the learning factories with respect to location, technological advancement in modern learning factories and also about some aspects of traditional training. As it is been told about training aspects in traditional training techniques it is always good to explain or compare it with some of the aspects of modern learning factory. The main problem faced by the traditional training technique was the financial factor which cannot be afforded by the companies at the time, mainly due to other organizational goals. In order to tackle these situations there are many ways in modern learning techniques, especially for small and medium industries. With the help of information and communication technology (ICT), there is no need for setting up a physical lab for training purposes, instead online or e-learning facilities can be used. As discussed above with the help of networking of association within the organizations, the level of knowledge sharing also increases which eliminates the need for in-house training sessions for the workers. The basic difference between new modern learning techniques over traditional techniques is the technological aspect, specifically the above mentioned ICT based system.

From the Figure 4.4, it is clear that the researches and studies regarding the modern learning factories were mainly carried out within the industrial and academic scenario. Data is collected from different international papers with respect to five types of learning scenarios of learning factories which can be clearly seen in the illustrated graph 4.4. The Graph 4.4 is plotted between the type of learning factories, the

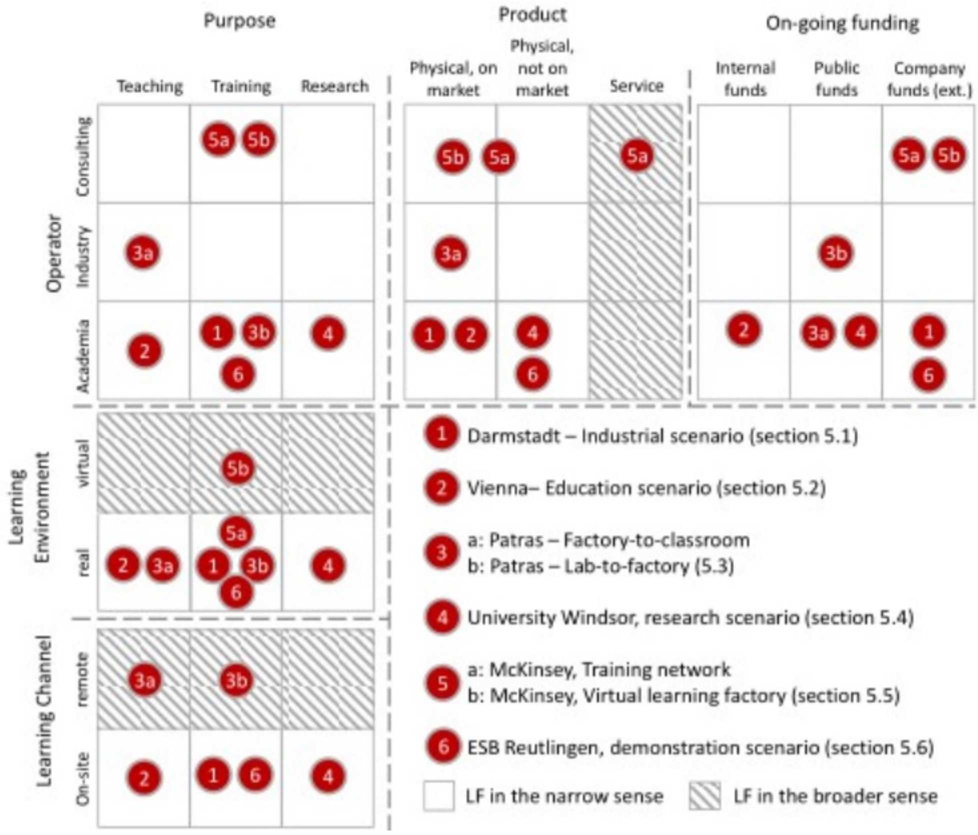

Figure 4.6: Learning Factories around the world with respect to scenarios [11]

country where the study was done and the amount of paper published with respect to place and type. Each box denotes the amount of research done by a specific country in the specific learning scenario. According to the data in Figure 4.4 and the knowledge from all the papers it is clearly shown that for the past few years at most importance is given for Academic and industrial learning scenario. This is mainly because of the preferences and needs of the industries for the future or might be because of some market driving strategies for some companies.

From the Figure 4.5 and 4.6, It is be able to see how learning factories around the world are distributed with respect to the different scenarios. The data taken from the figure is only used for the representation of the number of learning factories with respect to different purposes it is been used. With respect to limited data and the article mentioned, it is clear that there are six major different learning factories in different locations and 22 learning factory facilities. The major six learning factories and their concentrated area are TU Darmstadt- industrial scenario, TU Vienna- education scenario, Patras- remoter learning, University Windsor- research changeability, ESB Reutlingen- demonstration scenario and finally other 22 facilities are from McKinsey representing them as consultants for different purpose and service operations around the world. From the figure, even though it is able to get approximate number of learning factories around the world. But this numbers keep on changing due to the high potential and need for the learning factories.

It can be seen that there are researches going on changeability, remote and demonstration scenarios as well. But still, it is very less when compared to the other two type of learning scenarios. During the study, it is identified that industry based learning scenario and academy based learning scenario are the primary types of applications scenarios, upon which other learning scenarios are constructed. The main reason for considering industrial and academic scenarios as the primary learning factory scenarios are mainly because all other types of learning factory scenarios are linked to these primary scenarios either directly or indirectly. For example, if we are considering both remote learning scenario and consultant learning scenario, either scenarios have applications in academic as well as in industrial scenario. McKinsey learning factories is a good example as consultant who provides services and operations around the world. Even though they are consultants, their operations are mostly contributed towards educational and industrial purposes and this is same case with the remote learning as well. Learning factory towards the changeable scenario are very less when compared to others. From the fig 4.6 we could see that Windsor university facility is an example for changeable scenario but still the researches are going on how to implement it appropriately. From the data in Figure 4.1, we can see that research and study carried out is increasing with respect to the year. Thus, from the figure we can conclude that the research and study carried out are directly proportional to the technological advancement that is being developed in the present day to day scenario.

As today, the relationship between industry and academy is quite transparent and healthy which is reflected from the Figures and data acquired. With the limited knowledge attained from the study carried out. One of the suitable suggestions which can be considered for the future to make it bit broader, it is better to consider other options as well other than concentrating more on industrial or academic aspects of learning factory. As mentioned above, From the Figure 4.4 and 4.5 , we could see that enough studies aren't carried out with the changeability scenario. Changeability learning factory is a type in which it is more flexible than any other learning factories which support a system in which it is capable of supporting the improvement in the current system for the future. Therefore for supporting changeability scenario, organizations and industries should promote factories which support improvements and flexibility at their assembly line and other services. To support this kind of training concept it is applicable to perform more studies and researches on future changeability learning concepts.

4.2 Research Questions

1. What is the role of Learning factories in training a workforce capable of handling the new technology?

   Answer: The major part of the research carried out in the thesis is based on Learning Factories and its implications on the current Manufacturing sector. The study aimed to cover the evolution of technological advancements carried out over the centuries to the present scenario where the importance is to develop a well equipped and trained workforce. The different types of the Learning Factory concepts have been developed based on several requirements as per the goals of the stakeholders involved. The learning factory modules are advanced and are so capable that even the most complex technologies can be demonstrated along with being able to provide hands on experience to the engineers and other personnel involved with ease and simplicity. For example in the academic scenario, it can be very effective for the students to see and use the technology well ahead of being able to work with it in the industry. They are hence well prepared to meet the new challenges lying ahead.

2. What are the advantages of Learning Factories over traditional training techniques?

   Answer: Most of the data collected during the research were mainly based upon the modern learning factories. Therefore all the aspects covered during the study were about the technological developments and relationship between academia and industries. The major advantage of modern learning factory over traditional training is the advancement of the technologies what we have today. Traditional training is a setup where a person or group of persons are trained physical with respect to physical location and trainer. From the entire study, it is able to understand the main differences between the modern learning factory and traditional training. Other than this, some of the other advantages of modern learning factories over traditional way are real time data sharing, hands on experience with respect to real industrial environment, increased resources, helps to develop personal learning, increased accessibility for students and workers and finally methods are less time consuming when compared to traditional way.

5
Conclusion

The technological leap has forced companies into finding several ways to increase their productivity in order to stay in the competition. The technology leap is referred to a term most commonly known as Industrie 4.0. The study in this thesis concentrates on Learning Factories which forms an integral part of this technology leap faced by the companies in the process of transformation to the Fourth Industrial Revolution.

Findings from the analyze stage in the Grounded theory, it is observed that the important implications of the Learning Factories and its associated developments are leaning towards Industrie 4.0 and Cyber-Physical Systems (CPS). From the study and based on the sorting of articles from the conferences, it can be deduced that Germany leads in the research on Learning Factories as the concept of Industrie 4.0 was developed there. The study clearly indicates the role played by learning factories in training a workforce capable of handling new technology. The transition from traditional techniques of training to the sophisticated concept of Learning factory is a path that is to be taken up by most companies in order to ensure effectiveness in their production processes and a smooth transformation into Industrie 4.0.

Furthermore, it is seen that there is a shift in the manufacturing to the Asian countries, especially some of the East Asian and Latin American countries like China, Indonesia and Brazil played very important role in the field of manufacturing. The East Asian countries in particular, where effective in mobilizing and sustaining high rates of investments, which aided in the increased production processes [37]. Therefore, from the sorting of the articles based on the different learning factory scenario as per their respective locations, points out the countries that need to put more effort into the research regarding learning factory. This report forms a fundamental basis on which the study on Learning Factories can be formulated. As for the future, the ever evolving industry needs to be updated and well equipped. From the data and charts it is clear that changeability learning scenarios are very less when compared to industrial and academic. So as to meet the new challenges in future manufacturing industry it would be an added advantage if organizations can put more effort towards changeability learning scenario. Frequent changes occurring in terms of technological advancement are the main reason for considering more changeable learning environments in industries. From the study, it is confirmed that the research on Learning Factories depends on the location in which more importance are given for innovation and technological advancement.

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A

Appendix 1

SL No	Name
1	A-Two-way-Knowledge-Interaction-in-Manufacturing-Education–T_2015
2	Advanced-Learning-Factory–aLF—-Method–Implementation-and_2015
3	An-Interdisciplinary-and-Hands-on-Learning-Approach-for-Indus_2015
4	Competence-Development-for-the-Holistic-Design-of-Collaborative_2015
5	Competency-oriented-Design-of-Learning-Modules_2015
6	Concept-of-the-Green-Factory-Bavaria-in-Augsburg_2015
7	Cyber-Physical-Production-Systems-Combined-with-Logistic-Models–_2015
8	Designing-Learning-Environments-for-Energy-Efficiency-through-_2015
9	Developing-a-Learning-Factory-to-Increase-Resource-Efficiency-_2015
10	Die-Lernfabrik—Research-based-Learning-for-Sustainable-Prod_2015
11	Green-Factories-Bavaria–A-Network-of-Distributed-Learning-Fac_2015
12	Guideline-based-Video-Analysis-of-Competencies-for-a-Target-or_2015
13	Holistic-Approach-of-Lean-Thinking-in-Learning-Factories_2015
14	Industry-4-0-Learning-Factory-for-regional-SMEs_2015
15	Lean-Learning-Factory-at-FESB—University-of-Split_2015
16	Learning-Factories-and-their-Enhancements—A-Comprehensive-Tra_2015
17	Learning-Factories-for-Research–Education–and-Training_2015
18	Learning-Factory-2-0—Integrated-View-of-Product-Developmen_2015
19	Learning-Factory-for-Management–Organization-and-Workers–P_2015
20	Learning-Factory-on-Global-Production_2015
21	Learning-Integrated-Product-and-Manufacturing-Systems_2015
22	Multimedia-Support-for-Learning-Factories_2015
23	Project-based-Learning-in-Production-Engineering-at-the-Heilb_2015
24	Promoting-Work-based-Learning-through-INDUSTRY-4-0_2015
25	Realization-of-a-Learning-Environment-to-Promote-Sustainable-Val_2015
26	The-HOSHIN-KANRI-TREE–Cross-plant-Lean-Shopfloor-Manageme_2015
27	Value-Stream-Management-in-the–Lean-Manufacturing-Laborat_2015
28	Adaptation-and-Implementation-of-Modern-Learning-Techniques-in-Ma_2016
29	Additive-Manufacturing-for-Enhanced-Performance-of-Molds_2016
30	Application-of-Modern-Educational-Methods-through-Implementation_2016
31	A-Seamless-Convergence-of-the-Digital-and-Physical-Factory-Aiming-_2016
32	Atomistic-Modelling-of-Interfaces-in-Cold-Welded-Joints_2016
33	Benefits-of-a-Learning-Factory-in-the-Context-of-Lean-Manageme_2016
34	BERTHA—A-Flexible-Learning-Factory-for-Manual-Assembly_2016
35	Case-Study–Development-of-Social-Relations-for-Management–Lea_2016

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36	Combining-Learning-Factories-and-ICT–based-Situated-Learn_2016
37	Complementary-Research-and-Education-Opportunities-A-Comparison-_2016
38	Creation-of-a-Learning-Factory-for-Cyber-Physical-Productio_2016
39	Decentralized-Control-of-Logistic-Processes-in-Cyber-physical-Pr_2016
40	Distributed–Autonomous-Control-in-Production-of-Jet-Turbin_2016
41	Educational-Learning-Factory-of-a-Holistic-Product-Creation_2016
42	Enhancing-Integrative-Capabilities-through-Lean-Product-and-P_2016
43	ETA-Learning-Factory–A-Holistic-Concept-for-Teaching-Energy-_2016
44	EtherCAT-integrated-Processing-Machine-with-Full-Local-Task-_2016
45	Extending-the-Scope-of-Future-Learning-Factories-by-Using-Synerg_2016
46	Handling-of-Frequent-Design-Changes-in-an-Automated-Assembly-C_2016
47	Holistic-Approach-for-Human-Resource-Management-in-Industry_2016
48	Implementing-Cyber-physical-Production-Systems-in-Learning-_2016
49	Industrialization-of-Metal-Powder-Bed-Fusion-through-Machine_2016
50	Integrated-and-Modular-Didactic-and-Methodological-Concept-fo_2016
51	Integrating-Intralogistics-into-Resource-Efficiency-Oriented-_2016
52	Intelligent-Learning-Management-by-Means-of-Multi-sensory-F_2016
53	Lean-Learning-Patterns—CPD-nA-vs–KATA_2016
54	Learning-Factories-for-the-Operationalization-of-Sustainability-A_2016
55	Learning-Factory-Modules-for-Smart-Factories-in-Industrie-_2016
56	Manufacturing-Education–Facilitating-the-Collaborative-Learnin
57	Method-for-Configuring-Product-and-Order-Flexible-Assembly-Lin_2016
58	Model-Factory-for-Additive-Manufacturing-of-Mechatronic-Products-_2016
59	Multi-variant-Truck-Production—Product-Variety-and-its-Impact_2016
60	Preconditions-for-Learning-Factory-A-Case-Study_2016
61	Prototyping-to-Leverage-Learning-in-Product-Manufacturing-En_2016
62	Railway-Operation-Research-Centre—A-Learning-Factory-for-t_2016
63	Simulation-Game-for-Intelligent-Production-Logistics—The-Pu_2016
64	State-of-the-Art-of-Makerspaces—Success-Criteria-When-Designi_2016
65	Tangible-Industry-4-0–A-Scenario-Based-Approach-to-Learning-f_2016
66	The-MTA-SZTAKI-Smart-Factory–Platform-for-Research-and-Project_2016
67	The-Principle-of-the-Stored-Program-Applied-to-Servo-Motor_2016
68	Transfer-of-Model-of-Innovative-Smart-Factory-to-Croatian-Econ_2016
69	Using-a-Learning-Factory-Approach-to-Transfer-Industrie-4-0-App_2016
70	Using-Marker-less-Motion-Capture-Systems-for-Walk-Path-Analysi_2016
71	Agile-Learning-for-Vocationally-Trained-Expert-Workers–Exp_2017
72	An-Intelligent-Bin-System-for-Decentrally-Controlled-Intra_2017
73	A-Novel-Approach-for-Teaching-IT-Tools-within-Learnin_2017
74	A-Systematic-Approach-for-Designing-Learning-Environments-_2017
75	A-Web-based-Application-for-Classifying-Teaching-and-L_2017
76	Bridging-the-Qualification-Gap-between-Academia-and-In_2017
77	Capability-based-Task-Allocation-in-Human-robot-Coll_2017
78	Changing-Requirements-of-Competence-Building-Due-to-an-In_2017
79	Classification-of-a-Hybrid-Production-Infrastructure-in-_2017
80	Concept-Development-for-the-Verification-of-the-Didactic-Com_2017

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81	Critical-Competencies-for-the-Innovativeness-of-Value-Creati_2017
82	Demonstration-of-a-Concept-for-Scalable-Automation-of-Ass_2017
83	Developing-and-Harnessing-the-Potential-of-SMEs-for-Eco-_2017
84	Development-of-a-Model-for-the-Integration-of-Human-Facto_2017
85	Development-of-an-Optical-Object-Detection-Solution-for-D_2017
86	Development-of-Assembly-Systems-in-Lean-Learning-Factory_2017
87	Development-of-the-Industrial-IoT-Competences-in-the-Areas-of_2017
88	Digital-Twin-as-Enabler-for-an-Innovative-Digital-Shopfloor-M_2017
89	Employee-Qualification-by-Digital-Learning-Games_2017
90	Enhancing-Learning-Experience-in-Physical-Action-orientated-L_2017
91	Evaluation-of-Coaching-Success-for-the-Continuous-Improveme_2017
92	Experiencing-Closed-Loop-Manufacturing-in-a-Learning-_2017
93	HANDELkompetent—Situation-Aware-Learning-in-Reta_2017
94	Implementation-of-a-Learning-Environment-for-an-Industrie-4-_2017
95	Innovative-Approaches-for-Technical–Methodological–and-Soc_2017
96	Integrated-Product—System-Design-and-Planning-for-New-Pr_2017
97	Introducing-a-Maturity-Model-for-Learning-Factori_2017
98	Introducing-Competency-Models-as-a-Tool-for-Holistic-Competen
99	Knowledge-Based-Decision-Making-in-a-Cyber-Physical-Pr_2017
100	Lean-Stress-Sensitization-in-Learning-Factories_2017
101	Learning-Environment-to-Support-the-Product-Development_2017
102	Learning-Factories–Trainings-as-an-Enabler-of-Proactive-W_2017
103	Learning-Factory–The-Path-to-Industry-4-0_2017
104	Learning-in-the-AutFab—The-Fully-Automated-Industrie-4-0-L_2017
105	Modular-Smart-Production-Lab_2017
106	Planning-and-Evaluation-of-Digital-Assistance-Syst_2017
107	Potentials-and-Limits-of-Learning-Factories-in-Research–I_2017
108	Procedure-for-Experiential-Learning-to-Conduct-Material-Flo_2017
109	Roller-Skis-Assembly-Line-Learning-Factory—Developmen_2017
110	Simulation-Game-for-Lean-Leadership—Shopfloor-Managemen_2017
111	Standardized-Coordinate-System-for-Factory-and-Produc_2017
112	Teaching-Methods-Time-Measurement–MTM–for-Workplace-De_2017
113	Teaching-Smart-Production–An-Insight-into-the-Learning-Fac_2017
114	Textile-Learning-Factory-4-0—Preparing-Germany-s-Textil_2017
115	The-AAU-Smart-Production-Laboratory-for-Teaching-and-Resear_2017
116	The-Competence-Management-Tool–CMT—-A-New-Instrument-to-M_2017
117	The-Digital-Twin–Demonstrating-the-Potential-of-Real-Time_2017
118	Transition-towards-an-Industry-4-0-State-of-the-LeanLab-a_2017
119	Utility-based-Configuration-of-Learning-Factories-Using-a-M_2017
120	The Digital Twin: Realizing the Cyber-Physical Production System for Industry 4.0
121	Cyber physical systems in manufacturing
122	Cyber physical systems: extending pervasive sensing from control theory
123	Comparing effectiveness of elearning & traditional training in business environment
124	A model of developmental path of training in an organization
125	Training needs of in company trainers engaged the training of young people in Italy

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126	SAFARI:An environment for creating tutoring systems in industrial training