Aalborg University

Learning Factories for upskilling the workforce at SMEs towards Industry 4.0

Programme: Innovation Factory North

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PARADIGM

This thesis will identify research gaps through literature reviews and bring a focus on the industrial workforce of SMEs. The thesis will explore Learning factory as a method towards the transfer of knowledge of both Technologies and Technical competences and bring a method to measure the effect of a learning factory session.

Section 1. Project summary/abstract

Learning Factory as a concept, deals with the idea of transferring and creating of knowledge to the industry – this is focused towards both new players as well as incumbents. During the time of writing, the focus of the industry is towards the 4th Industrial Revolution – the connected industry – most often referred to as Industry 4.0 – and the idea of Industry 5.0/Labour 4.0, the human centred advanced production, is beginning to emerge in academic.

Industry 4.0 offers a wide range of possibilities, but where there are opportunities, there are also challenges. Through awareness seminars and workshops a focus have been set on the visionary, strategic and economic parts of the industrial sector - This has been carried out with the focus of Industry 4.0 topic and have been explored, both in general and with a focus on specific topics. But to move from an Industry 2.0/3.0 level to an Industry 4.0/5.0 requires both a willingness in investment, a courage to leave the well-known and several employees who share the vision of a new industry, based upon the old one. Industry 4.0 implementation is going to require a specialized workforce with a multidisciplinary mindset and an ability to work with a broader mindset than the specialization that have been educated over the last many years – a T-profile with both general focus on Industry 4.0 skills and an updated focus on their specialty. These employees need to gain knowledge about Industry 4.0 as well as their managers, it is the creation and transfer of this knowledge which is the focus of this thesis. For this, Learning Factories as a supporting transfer method will be examined. The focus will be to provide a broad understanding within the Industry 4.0 to the industrial workforce both on a operator and integrator level in the SMEs in North Jutland in Denmark. This will be supported by Learning Factory as a method for transferring knowledge to gain the technical skills necessary for the implementation of Industry 4.0 and to create new multidisciplinary knowledge in the industry of North Jutland.

The focus on the operator of Industry 4.0 technological production systems will require a focus on Learning (L), Training (T) and Assistance (A) when used – this can be shortened to an LTA method. Therefore, will the LTA method be investigated to support that a Learning Factory session in the task to upskill the operator level to a satisfied transition towards Industry 4.0 at the North Jutland SMEs.

This project is a part of Innovation Factory North (IFN), which will supply access to SMEs in North Jutland through Awareness, Demonstrator and Anchoring seminars.

Section 2. The scientific content of the PhD project

Background.

Innovation Factory North (IFN) is a cooperation between Aalborg University and industrial SMEs in the northern part of Denmark. The project is a base for an ecosystem for innovation based on Industry 4.0 technologies, data driven results and self-organising production systems. The ecosystem involves technology provides from the regional area, technology users (SMEs) and knowledge institutes to ensure an enforced focus on innovation and technology in the regions SMEs[1].

This PhD project main topic starts with the topic **Learning Factory**. But what is a learning factory and how can the topic support the goals of the IFN project. The concept of learning factories was published at the first Learning factory conferences (CLF) in 2010 and have been a concept focused on the idea of transferring knowledge of modern industrial production topics to both students as well as private companies. The basic idea is to give an understanding of the value of all aspects of a production chain from an order is received to the way through the factory floor and to the final product is shipped out – with a touch of all processes that happens through production.

A main topic of Learning Factories has been focused on the technologies and topics of **Industry 4.0** that were introduced as a high-tech strategy of the German government in 2011 – the idea was to ensure production stayed in Germany though the use of implementation of technology-based solution[2].

Awareness for **Industry 4.0** have been a strategy focus in the industry sector worldwide almost from the day it was introduced, with large companies as a spearhead while SMEs tried in smaller scale to implement the technologies and methods in their production. But a general picture is showing that on an operation level there is a gap in both knowledge and **technical Competences** in the industrial workforce at the companies – and that these gaps are a limiting factor in the implementation of the technologies to bring the production into an industry 4.0 era.

One of the *Labour 4.0* project conclusions is that a specific focus on the industrial workforce of SMEs and a focus on the here-and-now **technical competences** would clear the way for the mindset of industry 4.0 in SMEs. A little like "*How to eat an Elephant? One bite at a Time!"*[3]

Therefor will this PhD project focus on the industrial workforce of SMEs and explore **Learning factory** as a method towards the transfer of knowledge of both Technologies and **Technical competences** of **Industry 4.0** and bring a method to measure the effect of a learning factory and a LTA session.

[1] Innovation Factory North AAU - https://www.ifn.aau.dk/
[2] Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution - vdi-nachrichten.com - https://web.archive.org/web/20130304101009/http://www.vdi-nachrichten.com/artikel/Industrie-4-0-Mit-dem-Internet-der-Dinge-auf-dem-Weg-zur-4-industriellen-Revolution/52570/1
[3] Hogan, Bill:" How to eat an Elephant?: One bite at Time!" – 2011

State-of-the-art.

Industry 4.0 is a technology focused step towards the next industrial level [1, 2], and the subject have been discussed on a strategy level in many companies, small to big, over the last years with a high level of awareness [3]. But a recuring topics returns, multiple sources point at a lack of understanding of the impact of the technologies and the technical skills needed to lift a production to the level of industry 4.0[4, 5]. At the workforce level multiple sources points at this challenge to be based at the lack of a qualified workforce, knowledge about Industry 4.0, upskilling of employees and a understanding of the interplay between humans and technology as a limitation of the protentional of moving towards an industry 4.0 production system[4–9]. One of the challenges is that Industry 4.0 is a multi-disciplinary exercise with topics from multiple different discipline from both an engineering, business and design perspective[4]. Over the last many years, the educational system has focused on producing specialists, and the industry have had a tradition to place this specialist in different boxes – like Management, IT, Production, Operation etc. The main problem with Industry 4.0 and the multi-disciplinary nature of it, is that this will require that all the specialised disciplines of engineering will need to work together and with a professional overlap into the different specialties[3, 10]. This is where a new terms have start to emerge, Labour 4.0[3] and Industry 5.0[11] both terms with a human-centre focus – to be able to let the human workforce exist and operate next to highly connected and advanced technologies based on the Industry 4.0 era, in a human-technology based interplay[5, 12]. Based on these finding it can be concluded that a focus on the upskilling of the industrial workforce with a focus on the knowledge, technologies, interplay between humans and technologies and skills is needed to lift the SMEs in the northern part of Denmark to an industry 4.0. Therefore, will the focus of this PhD studies be on the industrial workforce and a way to bring them into the Industry 4.0 domain.

To work with and teach the mindset of Industry 4.0 a concept called Learning Factories emerge [13]. Learning factory is a concept, that in its base, are bringing participants through all the steps of a production – from raw components coming in to a final product ready for the customer[13]. The learning factories comes in many sizes and with different focus areas – but all of them has a common goal to bring different people together, and to give different specialists an understanding of all the steps in a modern/industry 4.0 production environment[13–15]. A learning factory is an ideal platform for introducing new technologies and concepts – it can be through an experience, hands-on sessions, learning paths via learning nuggets and demonstrations[13, 16, 17]. To work within the concept of learning factory and with a topic as broad as Industry 4.0(5.0) the need of collaboration across disciplines are higher than ever before[14]. This multidisciplinary cooperation of single disciplined specialist can benefit working with T-shaped profiled engineers, a specialist with broader understanding of other disciplines[18, 19]. The cooperation combinate with training via Learning factory session can support an interdisciplinary cooperation – a combined skillset that will support a complete Industry 4.0 production environment [18–20]. The learning factories is an interesting concept as a base together with the interdisciplinary idea of the T-profile for designing a framework with a focus on the transfer of knowledge to the industrial workforce towards a new industrial era.

Project objectives.

The projects main work area will be placed in the overlap between the knowledge of **Industry 4.0/5.0**, a medio for transfer and reflection of creation of knowledge though the concept of **Learning Factories** and a on the needed **Technical competences** to implement and integrate the next level of modern industrial production.

The initiated problem for the project has been formulated:

"How does Learning factories support the transfer and creation of knowledge within Industry 4.0, it's Technologies and the required Technical competences for handling these?"

To support the initiated problem, research questions has been formulated:

1. ***How can the effect of training via Learning factories be measured?***
    - *This problem will start based on the literature studies and go through an iterative process in cooperation with problem 2, from where the data from several Learning Factories sessions will be used to valet the designed method.*
    - *The learning factories session will include:*
        - *A Focus on a physical Learning factory setup*
        - *A Focus on a virtual (digital) training Learning factory session*
        - *Training on Learning Factory vs. side-by-side training on a "machine"*

2. ***How can a design framework, for an industrial workforce, be structed in a Learning Factory context and how can it be validated via empiric test?***
    - *This problem will start based on the literature studies and be a part of the iterative process, describe in problem 1. The focus will be on the industrial workforce of the Northern part of Denmark and will work with two methods:*
        - *The IFN project is using a method based on three phases: Awareness, Demonstrator & Anchoring. From multiple individual companies need, Demonstrators with an industry 4.0 specific topic are designed. These demonstrators will be investigated with a Learning factory focus.*
        - *LTA – Learning, Training & Assistants combined with Learning Factory as a method for setting up an LTA focused platform to train operators on new use of technology*

3. ***How can a digital Learning Factory support the transfer and creation of knowledge, acquiring of skills and obtaining of competences for working with Industry 4.0/5.0 tasks?***
    - *Can Visual Training support physical training in the Hands-on work with Technologies?*
    - *Can Visual Training replace physical training in the Hands-on work with Technologies?*

Key methods.

To establish a foundation of knowledge on the knowledge base within this research topic, a literature review will be conducted concentrating on the content of the knowledge base. To include the industrial relevance of the research, case studies will be made with participating companies from the IFN program. To ensure validity of research results an evaluation of cases and activities is necessary.

The project is a part of the IFN project, and within this project the activities are organized into three phases: “Awareness”, “Demonstrator”, and “Anchoring” which are repeated with different companies throughout the project’s life span. The content of the three phases is consistent with the three main phases of an innovation process, namely “idea”, “prototyping” and “implementation”.

This PhD will focus on the design of “Demonstrators” based on the reflection upon the “Awareness” phase, baring the three main phases in mind. Data for the project will come from the collected interview data from the IFN project – these interviews are being conducted and the data is collected by PhD students on the IFN project. This will give an empirical base and a validation for the specification and purpose of the second phase – the “Demonstrator”. In the Demonstrator phase, the concept of Learning factory will be examined as a method, with a focus on individual skill and knowledge adoption and anchoring. The LTA method will also be investigated as towards the Learning, training, and assistant of industrial operators.

Both the Learning Factory as a method and the LTA method will be suppling data to the PhD project via different measuring means. This will be done both through data collection doing a “demonstrator” session via observation and via structured interviews and surveys with the participant in the section. The goal will be to make a standardized method for measuring the output of a Learning Factory sessions. Furthermore, the experience from the designed learning factory prototype will be used as a fundament for suggesting a design framework.

The section will take place on the AAU Smart Production facilities supplied with added technologies relevant for the “demonstrator”.

Significance and outcome.

The thesis will identify research gaps through literature reviews and bring a focus on the industrial workforce of SMEs. The thesis will explore Learning factory as a method towards the transfer of knowledge of both Technologies and Technical competences and bring a method to measure the effect of a learning factory session.

Direct outcomes:

- Standardized method to screen participants skill level, before and after a learning factory session with a focus on the industrial Integrators of SMEs
- A training manual, based on the LTA method, focused towards industrial Operators
- Physical demonstrators focused on both industrial Integrators and Operators with a focus on both next level technologies and the technical competences needed to handle these.

Section 3. Work and publication plans

Work and Time Plans.

Year	2021			2022				2023				2024	
Quarter	2	3	4	1	2	3	4	1	2	3	4	1	2
Literature study													
Experiment design with a focus on measuring the effect of a learning factory scenario													
Executing experiments with Learning factories													
Development of method to screen Learning factory participants towards individual upskilling with in a I4.0/5.0 setup													
Designing a virtual learning factory													
Development of a custom learning platform, focused on industrial technicians													
Development of LTA based training scenario													
Design of experiment to comparing LTA and Learning Factory concepts													
Developing a digital twin solution to support learning and training of digital skills													
Writing the thesis													
PhD courses													
Publishing of papers			#1C		#2C		#3C		#4C		#5J	#6J	
Milestones				MS1	MS2	MS3	MS4		MS5		MS5	MS6	MS7

Activities finished	Activities being performed	Planned activities	Buffer time

MS1: Material selection.

MS2: Design of method for measuring effect of training

MS3: Having a demonstrator setup physical in the lab

MS4: Having a virtual demonstrator setup

MS5: Having a screening method for design of individual training

MS6: Having a set of twins, a digital and a physical, for supporting learning and training

MS7: Finalizing the thesis

Outline of thesis.

The outcome of the thesis will be presented as a collection of papers published within the lifetime of the PhD project. It will be accompanied by a concise, yet comprehensive summary report

The outline of the summery report is as follows:

PART 1: Introduction

- Motivation (initial problem statement)
- State of Art
- Research questions
- Research methodology

PART 2: Main findings and discussion – summary of papers

- Paper 1
- Paper 2
- Paper 3
- Paper 4
- Paper 5
- Paper 6

PART 3: Discussion and conclusion

- Perspectives on the research
- Concluding comments

Tentative publication list.

#	Preliminary title	Co-authors	Length Submission date	Published in
1	Measuring the effect of learning factory-based learning	Ole Madsen Astrid Heidemann Lassen Brian Vejrum Vaehrens	8 pages Q4 2021	Conference
2	Experience with learning factories for obtaining technical skills in the Industry 4.0 domain.	Ole Madsen Astrid Heidemann Lassen Brian Vejrum Vaehrens	8 pages Q2 2022	Conference
3	Experience with virtual learning factories	Ole Madsen Astrid Heidemann Lassen Brian Vejrum Vaehrens	8 pages Q4 2022	Conference
4	Building up customized learning processed for technicians in the domain	Ole Madsen Astrid Heidemann Lassen Brian Vejrum Vaehrens	14 pages Q2 2023	Conference
5	LTA vs learning factories	Ole Madsen Astrid Heidemann Lassen Brian Vejrum Vaehrens	14 pages Q4 2023	Journal
6	Use of digital twins to support learning and training in digital skills	Ole Madsen Astrid Heidemann Lassen Brian Vejrum Vaehrens	14 pages Q1 2024	Journal

Potential conferences to publish in:

- Conference on Learning Factories (CLF).
- Changeable, Agile, Reconfigurable and Virtual Production (CARV)
- IEEE International Conference on Industrial Engineering and Engineering Management
- CIRP Conference on Manufacturing Systems, CMS 2020

Potential journals to publish in:

- European Journal of Engineering Education.
- CIRP Journal of Manufacturing Science and Technology,
- International Journal of Computer Integrated Manufacturing.
- Technology in Society.

Section 4. Supervisor/student co-operation agreements

Roles:

Ole Madsen is the main supervisor. Astrid Heidemann Lassen and Brian Vejrum Vaehrens are co-supervisors. They will guide the progress of the project and provide support and feedback to the contents of the project.

Besides having an “open door policy” it has preliminary been agreed to have formal weekly meetings with the main supervisor and monthly meetings with the co-supervisors.

Project management:

Every month, the project plan will be reassessed and the degree to which milestones are met will be evaluated. If needed, modifications will be applied.

Knowledge sharing:

The PhD candidate should share the technical knowledge developed within the project with his supervisors and members of the Robotics and Automation and CIP groups. Furthermore, knowledge sharing will be done with UCN as well as a part of the IFN project.

The extent to which information is presented to other members is decided by the candidate as well as the supervisors. In this regard, requested activities are expected not to mandate excessive extra workload on the candidate.

Above agreement is not final and it can be revised during the project.

Section 5. Plan for PhD Courses (both general and project related courses)

Courses adding up to 30 ECTS credits must be outlined. Please use this table:

Courses	Place/Organized by	ECTS	General/Project course	Status
Introduction to the PhD Study	**AAU**	**0.5**	**General**	**Enrolled**
Applying the Danish Code of Conduct for Research Integrity to your Research	**AAU**	**1**	**General**	**Enrolled**
Basic Course with Focus on PBL	**AAU**	**2**	**General**	**Waiting**
Academic Writing in English	**AAU**	**2.5**	**General**	**Waiting**
Writing and Rewriting Scientific Papers	**AAU**	**3.75**	**General**	**Waiting**
Academic Information Searching, Publishing and Management (AISPM)	**AAU**	**2**	**General**	**Waiting**
Academic Writing in English	**AAU**	**2.5**	**General**	**Waiting**
Wireless Communications for industry 4.0	**AAU**	**2**	**Project**	**Waiting**
Scientific Computing using Python – 1. Python + Scientific Computing	**AAU**	**2,5**	**Project**	**Waiting**
Perspectives of Industry 4.0	**AAU**	**3**	**Project**	**Enrolled**
Conferences	**-**	**6**	**Project**	**Waiting**
Study group related to IFN	**-**	**3**	**Project**	**Waiting**
	Total	**30,75**		

Section 6. Plan for fulfilment of knowledge dissemination

Below, a summary of the main activities by the help of which the knowledge gained within the PhD project is expected to be shared internally and externally is presented.

#	Activity	Time
1	3 conference presentations	222 hours (1 week preparation, 1 week participation)
2	Supervision in 3 projects at AAU	195 hours (65 hours per project)
3	Teaching UCN	220 hours
4	IFN knowledge sharing	240 hours (1 day per month)
	TOTAL	875 hours

Section 7. Agreements on immaterial rights to patents

The PhD project will comply with the IPR rules via the standards of Aalborg University.

Section 8. External co-operation

The aim is to collaborate with a university or a research institute which is actively conducting research within the fields of learning factories and/or LTA. The period of staying abroad is expected to be between 3 and 6 months. Detailed information regarding the agreement with relevant institute will be addressed in 11-month plan. Meanwhile, research institutes in universities presented below will be investigated:

- University of Darmstadt (expertise in learning factories), Germany
- University of Windsor (expertise in learning factories), Canada
- Brandenburg Technical University (expertise in LTA), Cottbus, Germany

The PhD project is part of the IFN project, and collaboration with partners of the project is expected. Furthermore, collaboration with UCN is planned.

Section 9. Financing budget

The project is partly funded by IFN and partly as a collaborative research project with UCN.

Section 10. References

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