Learning Factory Morphology – Study Of Form And Structure Of An Innovative Learning Approach In The Manufacturing Domain

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ABSTRACT
In academia and industry learning factories are established as close-to-reality learning environments for education and training in the manufacturing domain. Although the approach and concept of existing learning factories is often similar, orientation and design of individual facilities are diverse. So far, there is no structured framework to describe Learning Factory approaches. In the paper a multidimensional description model is presented in form of a morphology which can be used as a starting point for the structuring and classification of existing Learning Factory application scenarios as well as a support for the development and improvement of Learning Factory approaches.

INTRODUCTION
The intensifying consideration of action- and experience-based concepts for competence development in the field of education and vocational training results in an observable range extension of close-to-reality learning and teaching environments. While so called *Learning Factories* for education of future production engineers are leading the way, educational strategies for other occupational sectors also adapt the idea of learning factories, such as the chemical and pharmaceutical industry (Wüst, 2011) or the service sector (Hammer, August, 28th, 2014).

Since there is no globally accepted definition for learning factories as an educational facility and no consent on the associated terminology, existing institutions which characterize themselves as such vary a lot, e.g. with regard to the available infrastructure, the underlying didactical concept and the level of realism. Understanding this broad range, characterizing single institutions and comparing those with one another is eased by description models. Within the third-party funded “Network of Innovative Learning Factories (NIL)” and the CIRP CWG “Learning Factories for future oriented research and education in manufacturing”, a new classification scheme for Learning Factories has been developed and tested. It intends to represent elements and features holistically. Due to the large numbers of institutions involved in the process, the result also claims a high degree of universal validity.

LEARNING FACTORIES FOR EXPERIENTIAL AND PROBLEM-BASED LEARNING IN THE MANUFACTURING DOMAIN
In the past, traditional teaching methods that have been applied in the manufacturing domain were not sufficient to meet the demands of the rapidly changing environments due to inadequate implementation and transfer effects for the manufacturing target groups (Abele & Reinhart, 2011). To avoid the obstacle of trainings being too abstract and far away from real manufacturing problems, manufacturing appropriate learning environments have been created in which self-learning processes can be initiated and moderated. In recent years, this approach has been implemented in industry and academia in form of learning factories (Abele et al., 2015). Depending on the perspective, learning factories are

- highly complex learning environments that allow a high-quality, self-contained competency development (teaching learning perspective) or

- idealized replicas of industrial value chain sections in which informal, non-formal and formal learning can take place (operational perspective) (Tisch, Hertle, Abele, Metternich, & Tenberg, 2015).

(Abele et al., 2015) give a short overview of the history of the Learning Factory approach from the early implementations at the Penn State University (Jorgensen, Lamancusa, Zayas-Castro, & Ratner, 1995; Lamancusa, Jorgensen, & Zayas-Castro, 1997; Lamancusa, Zayas, Soyster, Morell, & Jorgensen, 2008) over new Learning Factory variations especially in Europe (Abele, Cachay, Heb, & Scheibner, 2011; Wagner, AlGeddawy, ElMaraghy, & Müller, 2012) to the establishment of the Initiative of European Learning Factories (founded in 2011), the Network of innovative Learning Factories (NIL, worldwide, founded in 2013, funded by the German Federal Ministry of Education and Research through the German Academic Exchange Service (DAAD)) and the CIRP Collaborative Working Group on “Learning Factories for future oriented research and education in manufacturing” (CIRP CWG, worldwide, started in 2014). The understanding of the system Learning Factory in this article is based on discussions inside and the first results of the CIRP CWG on Learning Factories (Abele et al., 2015). The detailed description model presented in section 3 is developed in close cooperation with the NIL and the CIRP CWG.

EXISTING DESCRIPTION MODELS

Several classification and description models have been disseminated for the purpose of allowing a feature-based delineation of learning factories during the last three years (Initiative on European Learning Factories, 2012; Steffen, Frye, & Deuse, 2013b; Tisch et al., 2013; Wagner et al., 2012). They primarily use the heuristic procedure of morphologic analysis and either focus on particular technical aspects or at least hide out the didactical and pedagogical dimension.

Great asset of the morphological analysis (Zwicky, 1966, 1989) as a method for describing complex systems such as a Learning Factory is the integration of all significant features and characteristics and their potential attributes (Metternich, Abele, & Tisch, 2013). Thus, a picture of learning factories both holistic and generic can be drawn while at the same time a particular Learning Factory can be classified, allowing a simplified illustration of the correlations between all existing options to conceptualize a Learning Factory and the specific design of the actual Learning Factory that is being analyzed.

(Steffen et al., 2013b) present a morphology-based model that covers three contentual dimensions: operation model, target group/metrics and equipment. Thereby, the model is able to also describe framework conditions and information that do not necessarily concern the actual capability building process.

Additionally, (Steffen, Frye, & Deuse, 2013a) appended a didactics-focused description model that is making use of the same technique, but systemizing targets and contents of teaching and learning processes, design of the teaching situation and the organizational framework.

(Wagner et al., 2012) developed a classification tool for learning factories based on a decision table that retrieves information solely regarding the changeability of learning factories. It distinguishes between first- and second-order parameters: The first-order parameters prove if a certain change-enabler is true to the Learning Factory. If that is the case, the second-order level describes how this change-enabler is realized technically.

(Tisch et al., 2013) show a comparatively compact typology displaying a variety of Learning Factory parameters as the result from a survey of ten institutions that are part of the European Initiative on Learning Factories.

LEARNING FACTORY MORPHOLOGY

The developed description model of this paper is based on the definition and the dimensions of learning factories identified in (Abele et al., 2015):

- Operating Model
- Purpose and targets
- Process
- Setting
- Product
- Didactics
- Metrics

Since learning factories are evolving further as a result of new research findings in the educational context or due to emerging technology that has an impact on training needs, also description models need to be adapted or even extended constantly. Therefore, the CIRP CWG on learning factories as well as the project Network of Innovative Learning Factories (NIL), at the same time developed and validated a multi-dimensional description model. It can serve as an orientation in the design of a new Learning Factory as well as a tool for delineation of existing learning factories. As a compilation of features and characteristics that represent an academic consensus, the description model has a direct effect towards further standardization of the Learning Factory idea. Basically, learning factories are developed based on an underlying purpose through intended definition of curricula, equipment and a didactic model. For the description model developed, 59 single characteristics in seven dimensions were identified. Then, respective attributes have been developed and elaborated for each.

Part 1: Operating Model

Today's learning factories are mainly operated by academic institutions (Abele et al., 2011; Hummel, Schuhmacher, & Ranz, 2014; Reinhart, Schnellbach, Hilgert, & Frank, 2013; Sihn & Jäger, 2012) or profit-oriented operators, namely consulting firms (Hammer, August, 28th, 2014) and big industrial companies (mainly in the automotive industry (Herrmann & Stäudel, 2014; Oberthuer, 2013; Werz, 2012), but also in other sectors (Wüst, 2011)). In the non-profit oriented sector, a variation of the Learning Factory concepts is common in vocational schools (Zinn, 2014).
To operate a Learning Factory, it is not sufficient to have the sole Learning Factory equipment. Learning Factories create values in developing competencies over all hierarchy levels along the value chain in various technological and organizational fields. In order to not only built-up, but also continuously operate and improve the Learning Factory, it has to be linked with a sustainable operational model including financial, personnel and thematic quality/sustainability.
Learning factories must be financed initially (to build up the facility) and continuously (to enable the ongoing operation of the Learning Factory). For both types, internal, public and third party (company) funds from short to long term funding are possible for learning factories. As an important form of financing training programs can be offered on the market in open models (club model or course fees) or can be designed for individual companies.
Personal and organizational aspects play an important role in the quality of the Learning Factory concept. In addition to the technical expertise the Learning Factory staff requires didactic competence for the development and the moderation of trainings or the coaching of trainees. Suitable personnel (research assistants, engineers, etc.) must be recruited and developed.

<table>
<tr><td rowspan="2">1.1</td><td rowspan="2">operator</td><td colspan="3">academic institution</td><td colspan="5">non-academic institution</td><td colspan="2">profit-oriented operator</td></tr>
<tr><td>university</td><td>college</td><td>BA</td><td>vocational school / high school</td><td>chamber</td><td>union</td><td>employ-ers' asso-ciation</td><td>indus-trial network</td><td>consulting</td><td>producing company</td></tr>
<tr><td>1.2</td><td>trainer</td><td colspan="2">professor</td><td colspan="2">researcher</td><td>student assistant</td><td colspan="2">technical expert / int. specialist</td><td colspan="2">consultant</td><td>education-alist</td></tr>
<tr><td>1.3</td><td>develop-ment</td><td colspan="3">own development</td><td colspan="4">external assisted development</td><td colspan="3">external development</td></tr>
<tr><td>1.4</td><td>initial funding</td><td colspan="3">internal funds</td><td colspan="4">public funds</td><td colspan="3">company funds</td></tr>
<tr><td>1.5</td><td>ongoing funding</td><td colspan="3">internal funds</td><td colspan="4">public funds</td><td colspan="3">company funds</td></tr>
<tr><td>1.6</td><td>funding continuity</td><td colspan="3">short term funding (e.g. single events)</td><td colspan="4">mid term funding (projects and programs < 3 years)</td><td colspan="3">long term funding (projects and programs > 3 years)</td></tr>
<tr><td rowspan="2">1.7</td><td rowspan="2">business model for trainings</td><td colspan="5">open models</td><td colspan="5" rowspan="2">closed models
(training program only for single company)</td></tr>
<tr><td colspan="2">club model</td><td colspan="3">course fees</td></tr>
</table>

Figure 1: Learning Factory morphology part 1: Operating model

Part 2: Purpose and targets

In order to classify a system as "Learning Factory", learning in some sense has to be part of the concept. Following this, either education and/or vocational training (learning in the sense of competency development) and/or research (learning in the sense of innovation) is/are the main purpose(s) of a Learning Factory. As additional secondary purposes industrial production, demonstration and technology transfer, advertisement for production and testing are possible.

For the education and training various target groups in heterogeneous or homogeneous constellation and targeted industries may be addressed in learning factories. Also numerous fields of subject relevant learning content can be identified in existing learning factories, for an overview see also (Micheu & Kleindienst, 2014).

2.1	main purpose	education	vocational training	research												
2.2	secondary purpose	test environment / pilot environment	industrial production	innovation transfer	advertisement for production											
2.3	target groups for education & training	pupils	students			employees				managers			entrepreneurs	freelancer	unemployed	open public
			bachelor	master	phd students	apprentices	skilled workers	semi-skilled worker	unskilled	lower mgmt	middle mgmt	top mgmt				
2.4	group con-stellation	homogenous	heterogenous (Knowledge level, hierarchy, students+employees, etc.)													
2.5	targeted industries	mechanical & plant eng.	automotive	logistics	transpor-tation	FMCG	aerospace									
		chemical industry	electronics	construction	insurance / banking	textile industry	…									
2.6	subject-rel. learning contents	prod. mgmt & org.	resource efficiency	lean mgmt	auto-mation	CPPS	work system design	HMI	design	Intralogistics design & mgmt	…					
2.7	role of LF for research	research object	research enabler													
2.8	research topics	production management & organization	resource efficiency	lean mgmt.	auto-mation	CPPS	change-ability	HMI	didactics	…						

Figure 2: Learning Factory morphology part 2: Purpose and targets

Part 3: Process

In the third dimension "Process" of the description model potential system boundaries of learning factories regarding the product, factory, technology and order lifecycle (Bauernhansl et al., 2014) are described. Furthermore processes and functions are described in detail regarding the material flow, the process type, manufacturing organization, the degree of automation, manufacturing methods and technology.

3.1	product life cycle	product planning	product development	product design	rapid prototyping	manufacturing	assembly	logistics	service	recycling
3.2	factory life cycle	investment planning	factory concept	process planning	ramp-up				main-tenance	recycling
3.3	order life cycle	configuration & order	order sequencing	production planning and scheduling					picking, packaging	shipping
3.4	technology life cycle	planning	development	Virtual testing					main-tenance	moderni-zation
3.5	indirect functions	SCM	sales	purchasing	HR	finance / controlling	QM			
3.6	material flow	continuous production	discrete production							
3.7	process type	mass production	serial production	small series production	one-off production					
3.8	manufact. organization	fixed-site manufacturing	work bench manufacturing	workshop manufacturing	flow production					
3.9	degree of automation	manual	partly automated / hybrid automation	fully automated						
3.10	manufact. methods	cutting	trad. primary shaping	additive manufact.	forming	joining	coating	change material properties		
3.11	manufact. technology	physical	chemical	biological						

Figure 3: Learning Factory morphology part 3: Process

Part 4: Setting

The dimension "Setting" describes the represented learning environment and its features. The original idea behind the learning factories involves a physical factory environment where participants can experiment and explore. Here life-size and scaled-down (miniaturized) factory environments are observed, see e.g. (Abele, Tenberg, Wennemer, & Cachay, 2010; Festo Didactic, 2014). In addition to this, learning processes can involve virtual and digital representations of value adding chains (Sivard & Lundholm, 2013). The Learning Factory concept also enables good opportunities for blended learning programs, where the physical Learning Factory serves as an application scenario and a place where participants can meet (Tisch et al., 2015).

According to the definition, a Learning Factory includes more than one single work station (Abele et al., 2015) – a whole factory (or even a factory network) may be part of the learning environment. Flexibility and changeability are important requirements for this factory environment since trainees must be able to remodel it. Like in a regular factory IT-support is possible before (CAD, CAM, etc.) and after (ERP, MES, etc.) the start of production (SOP) as well as after the production phase (CRM, PLM).

4.1	**learning environment**	purely physical (planning + execution)	physical LF supported by digital factory (see line “IT-Integration”)	physical value stream of LF extended virtually	purely virtual (planning + execution)	
4.2	**environment scale**	scaled down	life-size			
4.3	**work system levels**	work place	work system	factory	network	
4.4	**enablers for changeability**	mobility	modularity	compatibility	scaleability	universality
4.5	**changeability dimensions**	layout & logistics	product features	product design	technology	product quantities
4.6	**IT-integration**	IT before SOP (CAD, CAM, simulation)	IT after SOP (PPS, ERP, MES)	IT after production (CRM, PLM…)		

Figure 4: Learning Factory morphology part 4: Setting

Part 5: Product

The product is a functional instrument in every Learning Factory and has to support the knowledge transfer through its inherent characteristics. In contrast to the regular product design process, the product used in a Learning Factory is either chosen intendedly from existing products on the market or is even developed specifically for the objected use (Metternich, Abele, & Tisch, 2013; Tisch et al., 2015; Wagner, AlGeddawy, ElMaraghy, & Müller, 2014). For this particular case, (Wagner et al., 2014) provide a development procedure for Learning Factory products. The product has an impact on the complexity of learning scenarios and their duration. It is also one driver of operational costs and affects efforts for maintaining and administering a Learning Factory. While most Learning Factories use dismountable products for repeated usage, some facilities also merchandise the Learning Factory production output after trainings, see e.g. (Kreimeier et al., 2014).

5.1	**materiality**	material (physical product)	immaterial (service)				
5.2	**form of product**	general cargo	bulk cargo				
5.3	**product origin**	own development	development by participants	external development			
5.4	**marketability of product**	available on the market	available on the market but didactically simplified	functional, could be available on the market	without function/ application, for demonstration only		
5.5	**no. of different products**	1 product	2 products	3-4 products	> 4 products	flexible, developed by participants	acceptance of real orders
5.6	**no. of variants**	1 variant	2-4 variants	4-20 variants	…	flexible, depending on participants	determined by real orders
5.7	**no. of components**	1 comp.	2-5 comp.	6-20 comp.	21-50 comp.	51-100 comp.	> 100 comp.
5.8	**further product use**	re-use / re-cycling	exhibition / display	give-away	sale	disposal	

Figure 5: Learning Factory morphology part 5: Product

Part 6: Didactics

An integral component of every Learning Factory concept is "Didactics". Beyond describing the learning outcomes and competence classes addressed, the methods used and the surrounding conditions to achieve those outcomes are detailed. Although learning factories per definition focus on action-oriented, also teacher-centered teaching methods may be incorporated in the overall concept. It should be kept in mind, that competencies generally are developed in an alternation of thinking and doing, while both elements are essential (Aebli, 1994).

6.1	competence classes	technical and methodological compentencies	social & communication competencies	personal competencies	activity and implementation oriented competencies		
6.2	dimensions learn. targets	cognitive	affective	psycho-motorical			
6.3	learn. sce-nario strategy	instruction	demonstration	closed scenario	open scenario		
6.4	type of learn. environment	greenfield (development of factory environment)	brownfield (improvement of existing factory environment)				
6.5	communica-tion channel	onsite learning (in the factory environment)	remote connection (to the factory environment)				
6.6	degree of autonomy	instructed	self-guided/ self-regulated	self-determined/ Self-organized			
6.7	role of the trainer	presenter	moderator	coach	instructor		
6.8	type of training	tutorial	practical lab course	seminar	workshop	project work	
6.9	standardi-zation of trainings	standardized trainings	customized trainings				
6.10	theoretical foundation	prerequisite	in advance (en bloc)	alternating with practical parts	based on demand	afterwards	
6.11	evaluation levels	feedback of participants	learning of participants	transfer to the real factory	economic impact of trainings	return on trainings / ROI	
6.12	learning success evaluation	knowledge test (written)	knowledge test (oral)	written report	oral presentation	practical exam	none

Figure 6: Learning Factory morphology part 6: Didactics

Part 7: Metrics

Ultimately, a metrics section describes quantitative figures easily ascertainable such as floor area size, average number of participants per trainings or the number of full time researchers assigned to the Learning Factory. It is supposed to give the user of the description model better vivid perception of physical and operational extent of the Learning Factory analyzed.

7.1	no. of participants per training	1-5 participants	5-10 participants	10-15 participants	15-30 participants	>30 participants	
7.2	no. of standardized trainings	1 training	2-4 trainings	5-10 trainings	> 10 trainings		
7.3	aver. duration of a single training	< 1 day	1-2 days	3-5 days	5-10 days	10-20 days	> 20 days
7.4	participants per year	< 50 participants	50-200 participants	201-500 participants	501-1000 participants	> 1000 participants	
7.5	capacity utilization	< 10%	10 – 20%	21 – 50 %	51 – 75 %	76 – 100 %	
7.6	size of LF	< 100 sqm	100 – 300 sqm	300-500 sqm	500-1000 sqm	> 1000 sqm	
7.7	FTE in LF	< 1	2-4	5-9	10-15	> 15	

Figure 7: Learning Factory morphology part 7: Metrics

RESULTS AND OUTLOOK

The presented description model, compiled by seven morphological boxes, integrates all scope areas relevant for characterizing a Learning Factory for education in the manufacturing domain. Through the high number of involved partners in the international development and testing process, it can not only be considered the most comprehensive description model for learning factories existing, but also the most generally accepted. Thereby, it is a contribution towards standardization and standard assurance in the Learning Factory context. Since further dissemination of the Learning Factory concept and thereby the set-up of new facilities are expected in the years to come, also some new distinction criteria may arise as a by-product of the evolvement. Thus, this description model is not a static construct but will be questioned consistently with regard to actuality and integrity and updated or expanded whenever necessary.

As a first next step, a web-based platform that allows operators of existing learning factories to assess their concept with the help of the presented morphology will be established. The platform will also serve as an information database for those who seek to identify a facility with certain desired features and thereby facilitate forging new contacts and creating new partnerships for Learning Factory operators and interested parties.

ACKNOWLEDGEMENTS

This material is based upon work supported by the German Academic Exchange Service (DAAD) through funds from the German Federal Ministry of Education and Research, project-ID 56268262. The authors would like to thank the project partners of the “Network of Innovative Learning Factories” and the participants of the CIRP Collaborative Working Group on “Learning Factories for future oriented research and education in manufacturing” for contributing to the content.

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