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A guide to develop competency-oriented Lean Learning Factories systematically

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Abstract

In the last decade, various lean learning factories were established in industry and academia around the globe. They are used for experience-based training, education, and practice-oriented research. Learning factories provide a reality-conform production environment as a learning environment. Processes and technologies of the learning factory are based on real industrial sites. Learning factories doesn't only contain single workplaces or machines, but changeable multilink value added chains. Trainees can test and discover lean approaches in this environment and experience the holistic range of technological, organizational, and social issues linked to the approaches. The main goal of learning factories is an effective competency development, i.e. the development of the participants' ability (including motivational and emotional aspects) to master complex, unfamiliar situations. In order to reach this goal a systematic approach for the competency-oriented design of learning factory courses and systems is needed. Such a competency-oriented approach for the development of lean learning factories is presented, integrating the conceptual design levels 'learning factory', 'teaching module', and 'learning situation'. This approach addresses issues of intuitively designed learning factories and therefore enables an effective development of intended competencies. As a result lean learning factories including teaching modules and learning situations meeting the requirements of industry can be designed with a reduced effort and an increased success in the transfer to real problem situations. Among others, a case study of designing a learning module in the environment of the process learning factory CiP in the field of "Lean Quality" is presented in detail.

Keywords: Design levels, competency development, learning lean

1. Motivation

Today's challenges in industry are ranging from the transformation to digitalized production systems over demographic change to highly competitive markets in general. In order to cope with those challenges companies need to enable quick adaptions to changed market conditions. This is strongly dependent on the employees' abilities to act in a self-organized and creative way in unknown problem situations [1]. When it comes to the effective development of competencies traditional teaching methods show limited effects. Practice-oriented learning approaches are often divided into work-based, work-connected and work-bound learning. Figure 1 shows existing and innovative learning approaches. In order to improve learning processes didactics, psychologists, and learning designers discuss intensely aspects of a successful modelling of learning processes – e.g. a high contextualization of the learning environment, motivational aspects or the activity of the learner.

The learning factory concept addresses those prerequisites for effective competency development exceptionally well, since it enables an active, situated learning, while learners solving authentic manufacturing problems in teams. Competencies in this case are defined as the general human dispositions to act reflective and self-organized. Also the learning factory concept is well suited to create an alternation of thinking and doing while both activities are crucial to effective learning [2]. When on the one hand the doing part is missing (which can often be observed in traditional education) the problem of inert knowledge arises, when on the

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other hand the thinking part is lacking, it leads to unreflective operationalize. Figure 2 gives an overview on the aspects of the successful learning process modelling coming from didactic and psychological approaches as well as the information how the learning factory concept includes and addresses those aspects.

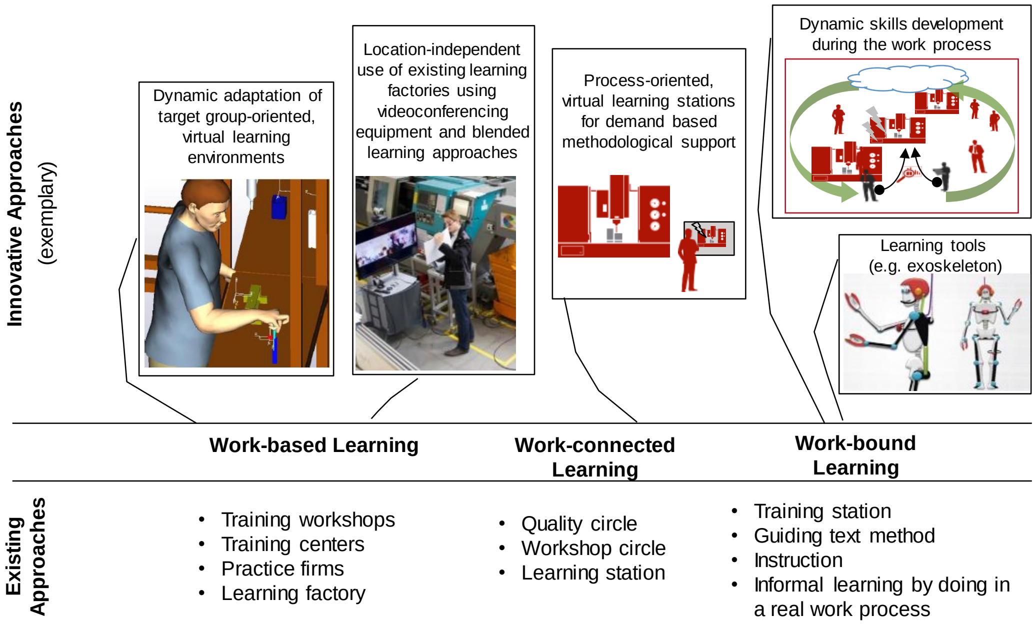

Figure 1: Exemplary existing and innovative learning approaches [1]

Because there is a wide variance of (learning) goals and requirements of learning factory systems, it is crucial that the learning system is tailored to the specific conditions. Since competency development is the main goal of learning factories, a competency-oriented approach to design learning factories systematically is needed. The following paper summarizes previous findings, especially [3, 4, 5, 6], to represent the holistic approach on different design levels.

Aspects of methodical modelling of successful learning processes	Learning factory as a learning system
Contextualisation, situated context	Partial model of real factory provides a rich learning context
Activation of learner	Generation and application of knowledge in the learning factory (learner active phases)
Problem solving	Solving of real problem situations in the learning factory
Motivation	Motivation by the reality character and the possibility to act hands-on immediately.
Collectivisation	Self-organised learning in groups is a suitable model in learning factories
Thinking and doing	Alternation of hand-on phases in the learning factory and systematization phases

Figure 2: The learning factory concept and aspects of successful learning processes according to [7] based on [2] [8] [9] [10] [11] [12] [13] [14] [15] [16]

2. Definition of Learning Factories

From the operational point of view, learning factories are value chain section models in which learning can take place. From the teaching point of view, learning factories are complex learning environments in which self-contained, high-quality competency development is enabled. The encyclopaedia of the International Academy for Production Engineering (CIRP) defines learning factories as follows [7]:

"A Learning Factory in a narrow sense is a learning environment specified by

- processes that are authentic, include multiple stations, and comprise technical as well as organizational aspects,

- a setting that is changeable and resembles a real value chain,
- a physical product being manufactured, and
- a didactical concept that comprises formal, informal and non-formal learning, enabled by own actions of the trainees in an on-site learning approach.

Depending on the purpose of the Learning Factory, learning takes place through teaching, training and/or research. Consequently, learning outcomes may be competency development and/or innovation. An operating model ensuring the sustained operation of the Learning Factory is desirable.

In a broader sense, learning environments meeting the definition above but with

- a setting that resembles a virtual instead of a physical value chain, or
- a service product instead of a physical product, or
- a didactical concept based on remote learning instead of on-site learning

can also be considered as Learning Factories."

Additionally a learning factory morphology that describes learning factory characteristics in details is identified [8]. Discussed intensely inside the CIRP Collaborative Working Group on learning factories, the morphology embodies an academic consensus on important learning factory features and is based on learning factory characteristics in the definition by [9] and [7]. It contains 59 characteristics that are detailed with corresponding typical attributes. The characteristics are divided into the seven clusters: Operating model, purpose and targets, process, setting, product, didactics, metrics. The categories are further described in Figure 3.

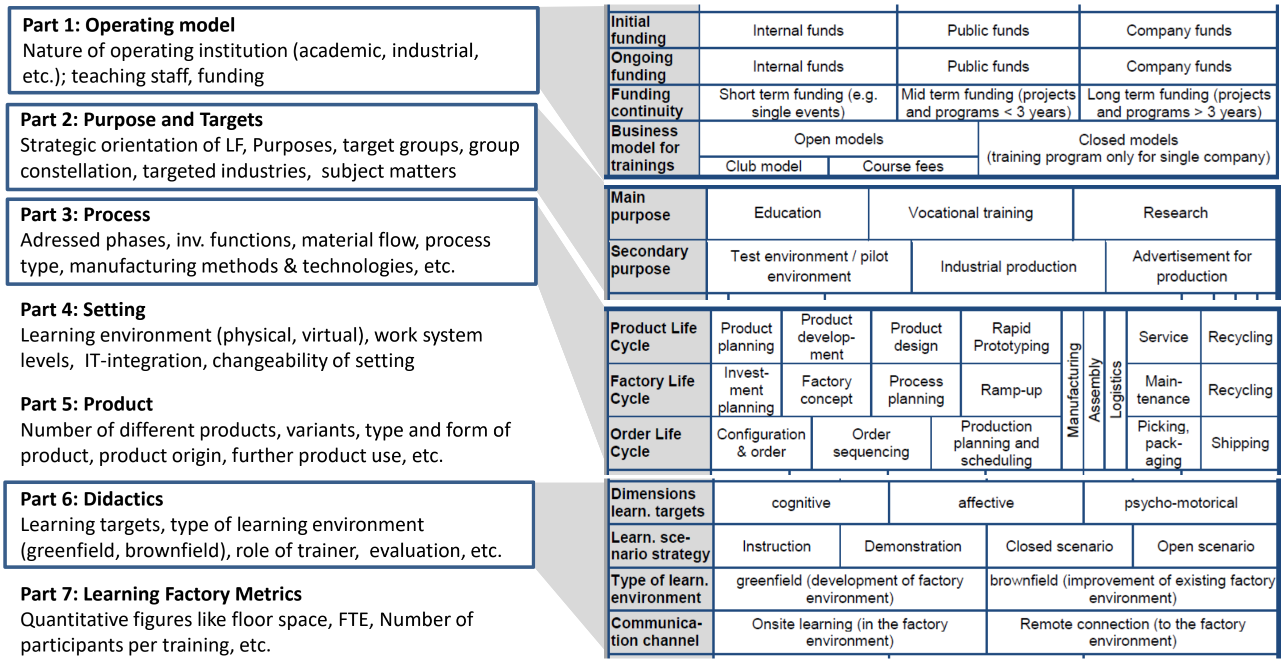

Figure 3: Selection of specific learning factory features in the morphology [9]

Based on this morphology, a web-based application is installed with the intention to collect information on learning factories around the globe in a structured way. The created application serves as an information database in order to identify learning factories with specific features. In this way new contacts and partnerships are enabled. New learning factory approaches can be inserted to the database at: http://syrios.mech.upatras.gr/LF/register. Figure 4 shows a screenshot from the database showing information on the Process Learning Factory CiP.

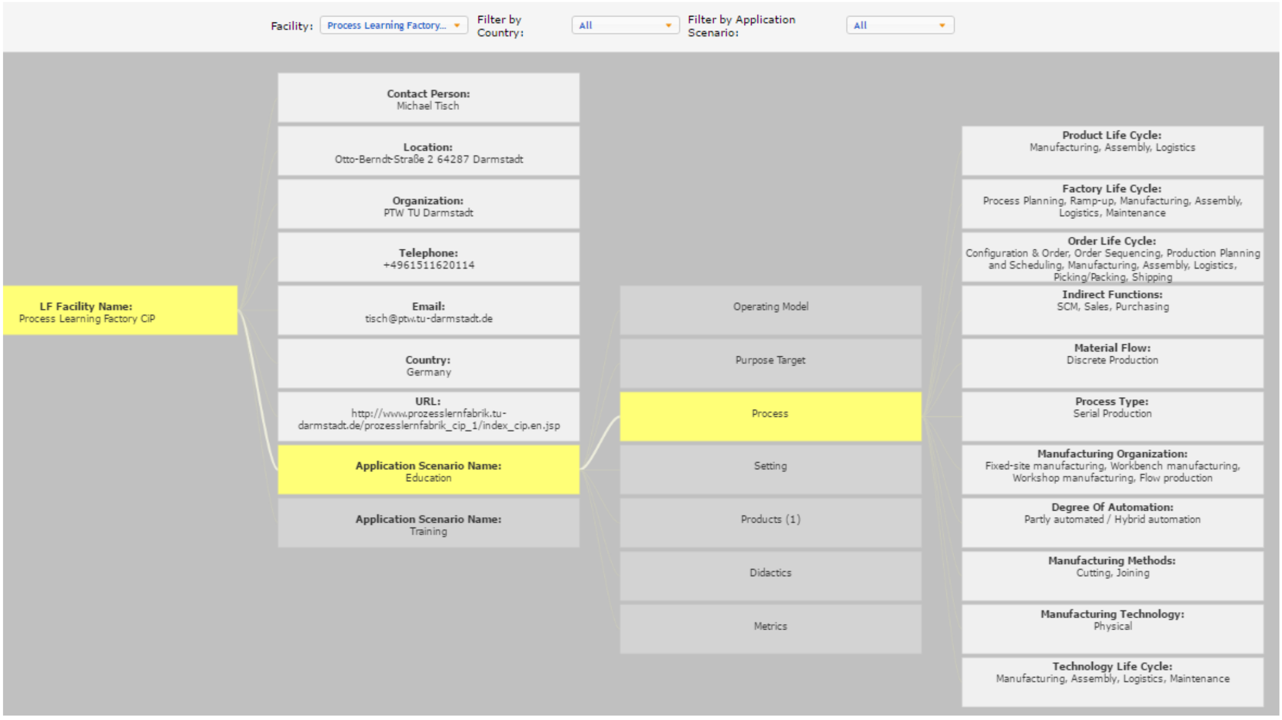

Figure 4: Screenshot from the learning factory database, exemplarily showing Process Learning Factory CiP

3. Competency-oriented development of Learning Factories

Typical learning factories as environments for competency development are designed by technical experts, focusing on a close to reality configuration of the processes, whilst disregarding didactical approaches for a more efficient gain of competencies. Due to a lack of knowledge about different options to arrange teaching-learning situations, only well-known didactic concepts are used. Educationalists are usually not involved in the design of learning factories. Furthermore, learning modules are created with no or little focus on the aspired learning objectives. As another result of a missing systematic approach in the general design pilot situations occur consistently, lowering the efficiency of the factory design process [3].

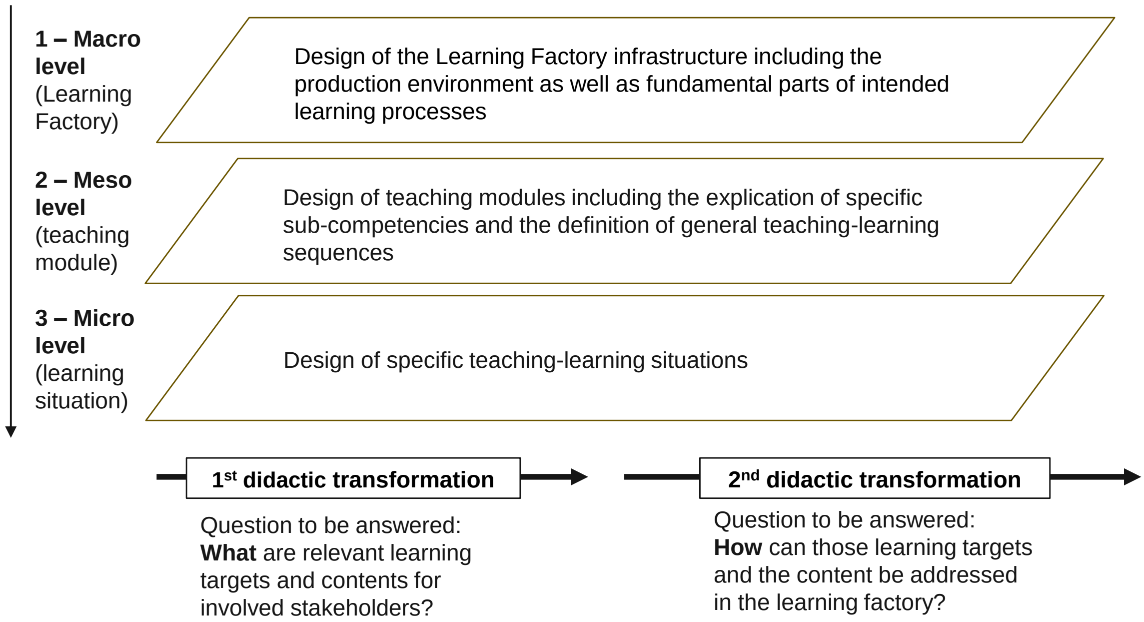

Figure 5: Levels of the learning factory design [5]

To solve the current problems related to the design of learning factories, a competency-oriented approach was generated. This approach addresses the learning factory on three different design levels: the macro level, the meso level and the micro level (see Figure 5). On the macro level, clarifying the learning factory environment, learning objectives as intended competencies are defined, serving as base for the configuration of the learning factory environment. The meso level defines the design of several teaching modules and covers hereby the formulation of sub-competencies and the planning of concrete teaching-learning sequences. Finally, the micro level serves the design of specific teaching-learning situations [5].

These levels are linked to each other. In one learning factory infrastructure several teaching modules are performed; one teaching module covers multiple learning-teaching sequences; for one sequence diverse teaching-learning situation have to be specified [5]. On each level two didactic transformations are executed. With the first didactic transformation the learning objectives (required competencies) are derived from the contentual, personal, organizational, and general requirements. In the second didactic transformation the defined learning objectives are transferred to a learning factory concept. The design of learning factories is mostly an iterative process, where feedback loops occur within the levels and between the different levels [5] – it is important to recognize where those feedback loops have to be foreseen. The different levels are now described in detail with the help of examples.

3.1. Macro level

On the macro Level the socio-technical and the didactical infrastructure need to be determined (Figure 6). The learning targets i.e. the intended competencies form the interface between first and second didactic transformation. In existing learning factories the focus lies on the development of technical and methodological competencies. Today´s learning factories are adressing for example the following learning targets: lean management, maintenance, automation, energy efficiency etc. (see also

Figure 7). Learning targets are derived from the organizational requirements, defining which competencies are needed in context of the organizational environment, organizational targets and target groups the learnings factory wants to address. The organizational environment could be high cost pressure or quality issues; organizational targets could be short innovation cycles, waste reduction or performance leadership etc. In the background of the definition of learning targets also the operating organization plays a significant role [4]. Based on the organizational environment different types of production can be identified and considered, for example batch production, mass production, etc. The organizational targets will strongly depend on both: the environmental challenges and the production type and need to be clearly stated before target groups and learning targets have to be defined. Target groups are depending amongst others on the operating organization and the organizational targets. Possible target groups are students, pupils, employees on different hierarchy levels or consultants.

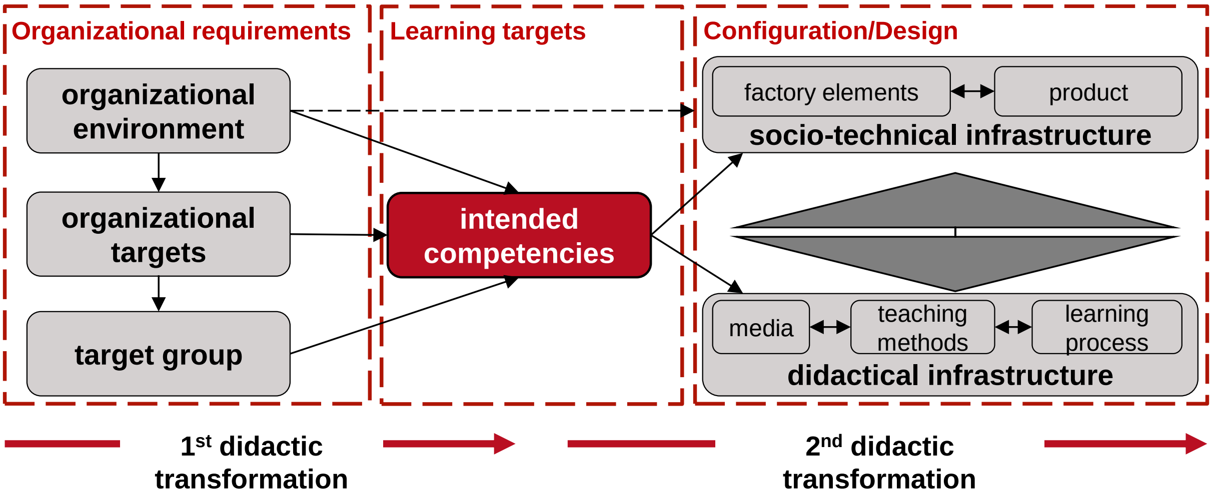

Figure 6: Elements and relations on the macro level [5]

On the basis of the learning targets the configuration and the design of the socio-technical and the didactical infrastructure are executed. The factory elements include the selection of a factory and product lifecycle the learning factory should map. This lifecycles are also dependent from the organizational environment (due to the industry which the learning factory should address). Furthermore, the socio-technical infrastructure covers the design of work stations, work cells, productions segments etc. in different states of improvement. In addition the socio-technical side includes the selection of a suitable product which satisfies didactical as well as economical requirements and is close to reality [5] [4].

The socio-technical infrastructure interacts with the didactical one. They can limit each other and their design has to be compromised between authenticity and universality, since the first one decides on the potential of effects of the learning environment and the second one on the flexibility of use [4]. The didactical infrastructure determines which teaching methods and supporting media are used to suit the development of intended competencies. Criteria for the teaching methods are for example role of the instructor, type of learning process, material resources, etc. For more criteria and examples refer to [3]. Moreover the didactical infrastructure describes the theory- and practice-oriented learning processes, which should take place in the learning factory. Theory-oriented learning processes use methods to systematically structure and impart knowledge. Practice-oriented learning processes use particular methods to create a stimulating learning enviroment in which testing, exploring and gaining experience is possible. Micheu and Kleindienst [10] give an overview of the operating organization and target groups (organizational requirements), the learning targets as well as the used product, the represented operating divisions and the used workplaces and equipment (socio-technical infrastructur) which can be identified in existing learning factories.

Figure 7 shows an extract from the results of this study.

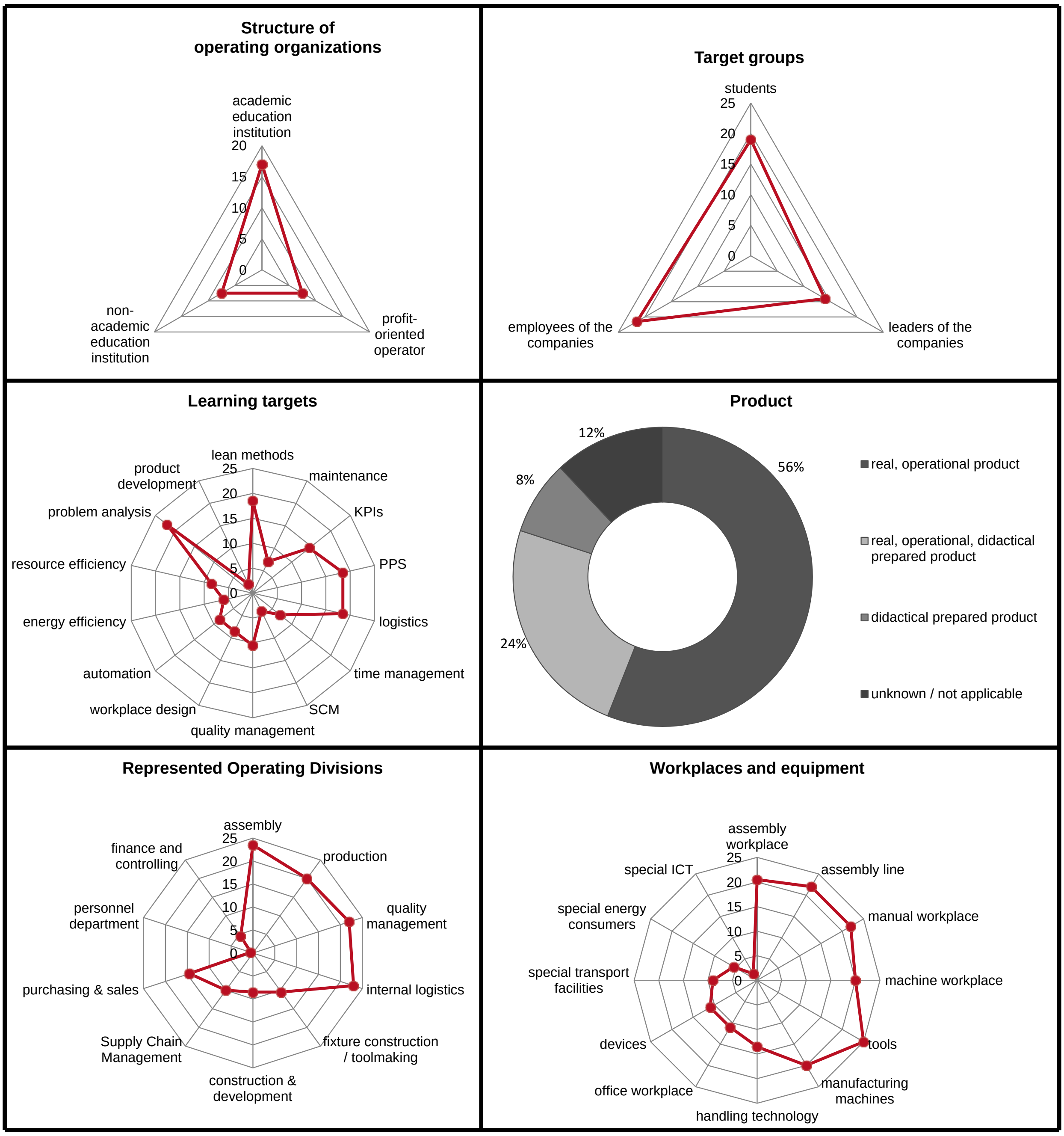

Figure 7: Organizational requirements, learning targets and socio-technical infrastructure of learning factories (extract from [10])

3.2. Meso Level

On the meso level learning modules are designed. Here a competency transformation chart can be used to record the results of the first didactic transformation. This chart is arranged as shown in Table 1. The first column states the superior competency which the learning module wants to develop. This competency is derived from the intended competencies, defined on the macro level.

Table 1: General framework of a competency transformation chart of a learning module [3]

Competency	Topic 1	Sub-competency 1	Corresponding action	Knowledge base
	Topic 2	Sub-competency 2.1	Corresponding action	Knowledge base
		Sub-competency 2.2	Corresponding action	Knowledge base
…	…	…	…	…
		…	…	…

The competency is divided in several sub-competencies as learning targets for the module which can be allocated to different topics, if the learning module covers a wide range of content. Next, corresponding actions and knowledge related to the sub-competency are listed. The knowledge base can be divided in different categories: technical and process knowledge as well as conceptual knowledge. All types of knowledge should be considered while designing a module. This approach ensures the didactical orientation of learning modules. Furthermore, it supports a systematical structure and guarantees that the knowledge correspond with the actions and therefore with the desired competencies. Unnecessary actions and knowledge are not executed or addressed during the performance of the module [3].

Table 2: Extract from the competency transformation chart of the learning module „Quality techniques of Lean Production“

Competency	Sub-competencies	Action	Knowledge base
The participants have the ability to explain the methods and tools for the implementation of Jidoka* and for the solution of problems and to apply selected methods and tools.	…	…	…
	Ability to develop an Andon-concept for Production	Design of an Andon-system (physical implementation)	Knowledge, that visual and acoustical signals and an Andonboard are needed; knowledge of the examined workplaces; knowledge of the functionality of Andon; knowledge of the meaning of the colors
		Planning of an escalation process for the problem escalation with Andon	Knowledge of the person in charge and of the available time; knowledge of the theoretical sequence of an escalation process (point in time for information, order of notification)
	…	…	…

Table 2 pictures an example from the learning module “Quality techniques of lean production” from the learning factory CiP. The aimed competency for this learning module is reflective application of methods and tools of Jidoka, one part of the Toyota Production System which deals with the elimination and prevention of defects and rework. One sub-competency the participants should establish during the learning module is the ability to develop an Andon-concept for production (Andon: stop production in case of an abnormal condition, alert and escalate). The identified, corresponding actions and a selection of required knowledge to this sub-competency are also listed in the table. Two actions are executed self-organized, to solve the problem of a missing Andon-concept in the production department of the learning factory CiP. First the learners should design an Andon-System physically. Next, they should plan the escalation process with the given boundaries and conditions in the factory. The knowledge indicated in Table 2 is technical and process knowledge. In the theoretical sections of the learning module only the specified knowledge should be addressed. The practical exercises in the learning factory cover the actions. For the creation of the competency transformation chart relevant literature is used as information basis [6].

Experimentation and exploration activities as learning activities are related to professional performance, for example to generate professional information material, to solve job-related problems, to formulate, achieve and review targets. While exploration means to find something new to inform about and deal with, experimentation includes application, implementation and realization. If the systematisation activity is executed before the experimentation activity, this would be a theory push, where theory on a certain topic is imparted and the participants solve a problem situation in the learning factory afterwards. The other sequence of activities is called problem pull: an unknown problem situation occurs, which the participant tries to solve (exploration). Afterwards theory is imparted and the suggested solution is tested in the learning factory.

Finally, reflection and (optional) examination activities are carried out. With this activities information can be gathered of the participants and the trainers regarding the effectiveness of the competency development through a target-actual comparison. From this comparison consequences can be derived, initializing further development of the learning module. Hereby, reflection is oriented toward the learners and provides the opportunity for them to check if their actions were right or wrong. In contrary, examination is oriented toward the trainer and implies also assessment [4].

Figure 9 presents the sequence of activities, which is used in the learning module "Quality techniques of Lean Production" to establish the sub-competency „Ability to develop an Andon-concept for production". The introduction integrates the concept Andon in the over-all topic of the module, Jidoka. Furthermore, the systematisation activity, which covers the theoretical input regarding Andon, is executed before an experimentation activity, which addresses the development of the Andon concept in the learning factory. The sequence closes with a reflection activity, which implies the presentation and discussion of results and a debate about the concept in general. An examination is not conducted.

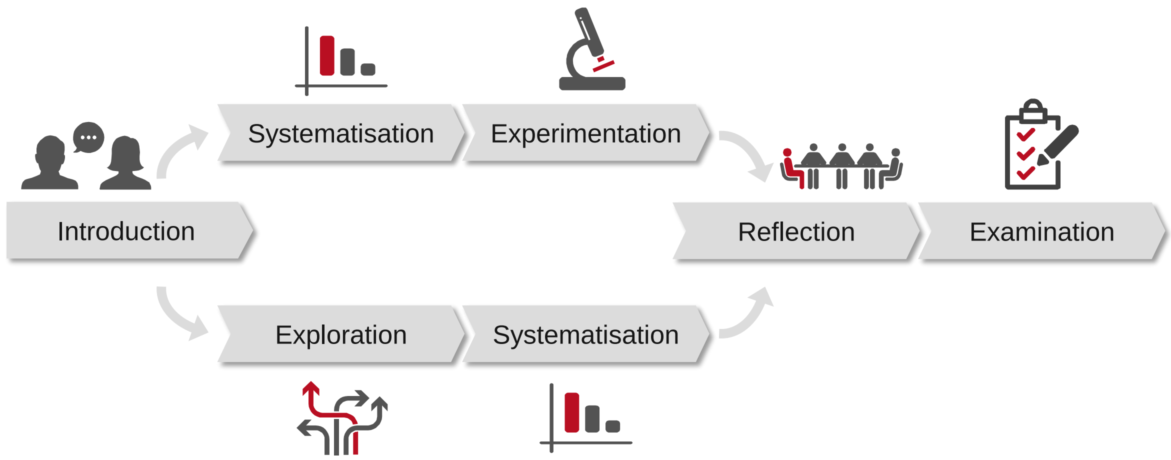

Figure 8: Possible sequences of activities, according to [4]

Figure 9: Sequence of activities for the sub-competency „Ability to develop an Andon-concept for production"

3.3. Micro level

On the micro level the several learning activities are specified in detail. The competency transformation chart serves as basis. After the identification of the necessary actions on the meso level, a scenario is designed which requires the execution of these actions. The intended competencies are demanded as the participants have to solve a problem and achieve a requested target self-directed in an unknown environment (the learning factory). Figure 10 shows an exemplary creation of an action exercise for the learning module "Flexible Assembly Systems". The addressed competency is the ability to implement the flexible assembly system. Step 1 of the figure shows the relevant extract from the transformation chart. Based on this, step 2 states the sequential actions the participants have to fulfil. For example the first action for the named competency is the creation of a rough implementation plan. Step 3 covers the creation of an assignment for the action exercise [11, 12]. The previous developments didn´t include the content-related or methodical elaboration (second didactical transformation). Now design elements are chosen and synchronized: media, methodical design, learning products, interaction planning and material. Hereby the following explications and aspects should be considered. Media supports the learning; teaching and learning media can be chosen; examples for media are presentations, production facilities, components, models, drawings, etc. Learning products materialize the learning process. Here sketches, notes, inscribed flip charts, filled work sheets and answers should be named as examples. The methodical design implies the selection of learning and teaching methods with appropriate design tasks. Interaction planning defines the interaction between trainers, media and participants; for example teamwork, single work, partner work or ex-cathedra teaching. Finally, materials are everything that regulates the learning (work sheets, script, templates, etc.) [4].

4. Conclusion

Learning factories were established in the last decade as a place for innovative (further) education for students and employees. For learners as participants in trainings they offer the opportunity for self-directed learning in a real factory environment. New competencies are developed by transferring proven concepts to unknown problem situations. For this purpose the participants use their available knowledge and act in a new environment. Most existing learning factories were build-up by technical experts. Therefore, didactical approaches or educational considerations are mostly not taken into account. This lowers the effectiveness of competency development, one of the core targets of learning factories. The paper presents a guide to develop learning factories systematically, considering a competency orientation.

The guide introduces three different level of learning factory development. The macro level includes the design of the general infrastructure (technical and didactical) as well as the definition of organizational boundaries and intended competencies as learning targets. The meso level addresses the configuration of several learning modules. Didactic transformations are executed with the help of competency transformation charts. Also sequences of learning activities are determined on this level. Finally, the micro level covers the structure of specific learning-teaching-situations. Furthermore, the learning elements are defined, that serve this situations best. The orientation on the intended competencies crosses all levels, increasing the effectiveness of their development in learning factories.

Such a systematic approach makes it also possible to measure the effectiveness which is important for further developments of learning factories, learning modules and teaching-learning situations. Competencies cannot be observed for this measurement, but actions can. Also knowledge can be tested. The results from observations and tests can be used to continuously develop learning factories in a competency-oriented way.

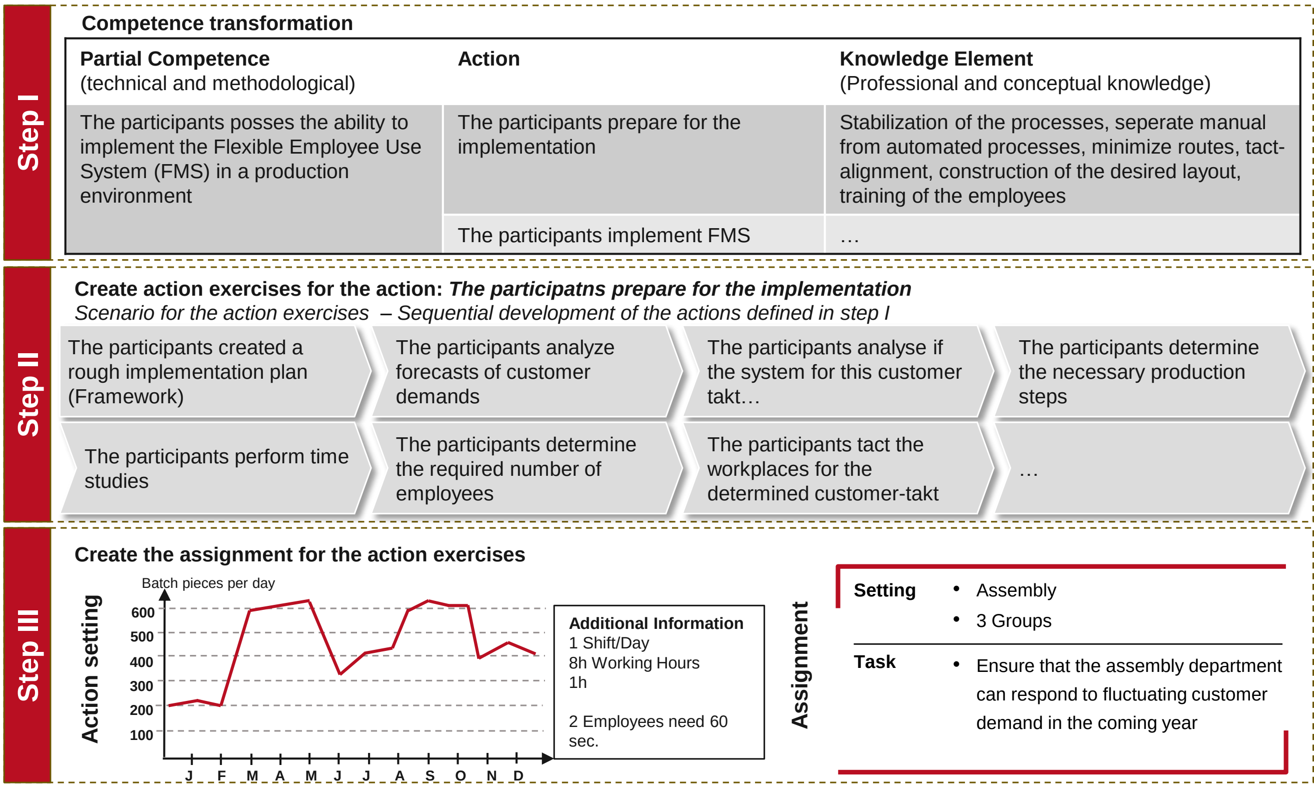

Figure 10: Example for the creation of action exercises from the learning module „Flexible Employee Use System" [12]

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