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# Aligning vocational training to the electromobile transformation by establishing the "Training Factory Stator Production" – A methodical deficit analysis with derivation of measures

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**Abstract**

In addition to the current challenges in production technology due to the shift from conventional powertrains towards electrified drive technologies, the disruptive transformation of mobility confronts OEMs and suppliers with major personnel challenges, which include new requirement profiles for prospective skilled workers. In order to meet the personnel requirements of industry and ensure the high quality of vocational training in Germany nonetheless, the current training concepts must be strengthened by the targeted integration of specific contents and be geared holistically to the needs of new occupational profiles. This paper presents a methodological approach for deriving current deficits in vocational education and training through the systematic analysis of framework curricula and the targeted survey of teachers working at German vocational schools as well as the derived training program to support the qualification of trainees. In order to obtain a training concept of high didactic quality, the approach is based on pedagogical methods to provide the best possible support and to convey the learning objectives related to professional, social, methodical, and personal skills. With the newly conceived "Training Factory Stator Production" at the wbk Institute of Production Science of the Karlsruhe Institute of Technology, a program for the training and further education of trainees, skilled employees and engineers will be introduced using the example of producing stators with hairpin technology, to support especially small and medium-sized companies in the personnel transformation process.



*Keywords:* Educational training concept; training factory; electric mobility; stator production; hairpin technology

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## 1. Introduction and motivation

Driven by restrictive emission standards of the European Union, the finite nature of fossil fuels and not least the growing public environmental awareness, a constant change in individual mobility from fossil combustion technologies towards renewable, electrified drive concepts can be expected in the coming decade [1]. This is accompanied by far-reaching changes in the automotive production and value chain resulting in new challenges in the field of product development and production technology [2]. Independent of the type of energy storage system used, traction drives play a central and performance-determining role in electrified vehicles and are therefore strongly affected by this transformation process. The process chains used for the production of electric traction drives differ considerably from the previous production of combustion engines and in particular show a considerably lower proportion of machining processes [3], which is why the engineers and skilled workers involved need to receive appropriate further education in the form of training courses and educational materials [4].

To meet this need for action, training concepts of high didactic quality are developed at the wbk Institute of Production Science at the KIT within the research project "Ausbildungsfabrik Statorfertigung"[1] and implemented by a series of courses. On the basis of holistic training measures in the context of producing electric traction drives, the previous training contents of the metal and electrical industry can be expanded without fundamental restructuring by teaching those skills required as a result of the ongoing transformation process towards electric mobility. Concepts based on vocational pedagogical principles address the qualification of trainees in particular, and they can, however, be extended to the possibility of training for skilled workers, engineers and managers due to their modular structure. As the hairpin technology offers great potential to meet the quality and productivity requirements of the automotive industry, the practical contents of the "Training Factory Stator Production" were implemented using this specific process as an example [5]. In addition, the process features similarities with previous process chains, which facilitates the entry into the production of electric traction drives. The hairpin technology describes a production process to manufacture stators for electric traction motors where the complex and time-consuming process for manufacturing the winding from round wires is replaced by forming U-shaped coil elements open on one side – the so-called Hairpin Coils or Plug-in Coils – made of a comparatively solid copper conductor with rectangular cross-sectional area as well as their subsequent assembly and contacting (see Fig. 1).

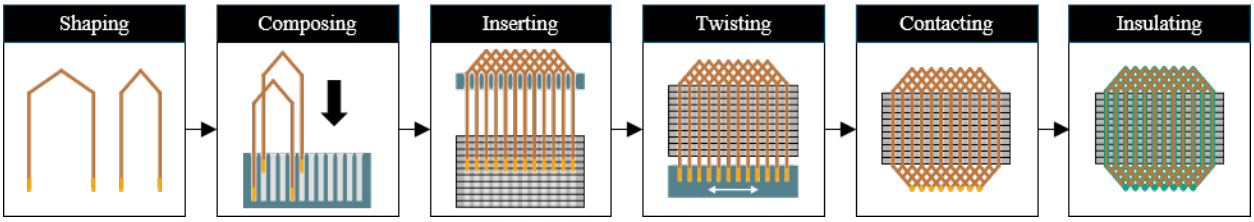


Fig. 1. Simplified process chain for the manufacturing of stators with hairpin technology.

## 2. Fundamentals and state of the art

### *2.1. The dual system of vocational education in Germany*

The dual system of vocational education and training in Germany describes a special model of international and European education and vocational policy, the main feature of which is the duality of vocational training institutions

[1] The research project "Ausbildungsfabrik Statorfertigung" is part of the Transformation Hub Electric Mobility established by the Karlsruhe Institute of Technology and funded by the Ministry of Economics, Labor and Housing of the Federal State of Baden-Württemberg in Germany.

through cooperation between predominantly small and medium-sized enterprises on the one hand and publicly financed vocational schools on the other. A further aspect is the division of legal responsibilities in such a way that the vocational schools, as municipal institutions, are subject to the legislation of the federal states, whereas the training companies, as private-sector companies, are themselves responsible for providing training, and they are subject to federal legislation [6]. While the training regulations represent the uniform federal standard for the objective and temporal structure of training in companies, the framework curricula contain the learning content of vocational education and training and define the competences to be acquired in dual training as well as the teaching contents of vocational schools. The (school related) organizational unit of vocational education and training is the "learning field", which is derived from the real fields of action of technical work. The learning field contains a target formulation of the competences to be learnt in it, which are based on job descriptions. In addition, a catalog of specific contents is attached to these descriptions, which summarizes the thematic learning content in key words, in contrast to the formulation of objectives.

### *2.2. Learning factories*

According to the definition of the CIRP Encyclopedia of Production Engineering, a "learning factory" is an authentic learning environment based on the necessary process steps of manufacturing a real product which provides direct access to the product development process. A learning factory depend on a didactical concept which comprises formal, informal and non-formal learning and emphasizing experimental and problem-based learning through interactive actions of the participants. [7] In the last decade several learning factories have been established, mainly in the fields of "Industry 4.0", lean manufacturing, agile production, logistics and energy efficiency [8]. In addition, the target groups of the existing learning factories have so far been primarily the higher management, specialists and engineers, while apprentices and vocational school teachers have rarely been focused. In the field of electric mobility, the focus is on management consulting or providing a technical overview of vehicle and drive technologies as well as the basic construction of electric vehicles [9]. Although more and more pilot projects for the theoretical training of skilled workers in the after-sales sector with regard to the new requirements of electric mobility have been launched in recent years, e.g. in form of e-learning platforms [10], there are no comparable offers which convey the necessary theoretical and practical knowledge at the manufacturing process level in an environment similar to a learning factory, especially in the area of production technology.

## 3. Methodology and approach for deriving training concepts of high didactic quality

In order to establish the "Training Factory Stator Production" as an optimal supplement to the German dual educational system with regard to the new requirements of electromobile transformation, the training concepts were developed according to the approach shown in Fig. 2. The methodology consists of three main phases. At first a competence analysis of the stator production with hairpin technology was carried out to identify all required qualifications and capabilities of skilled workers in relation to the manufacturing processes. The results were then used to compare the current vocational training with the necessary requirements of the automotive industry and to identify

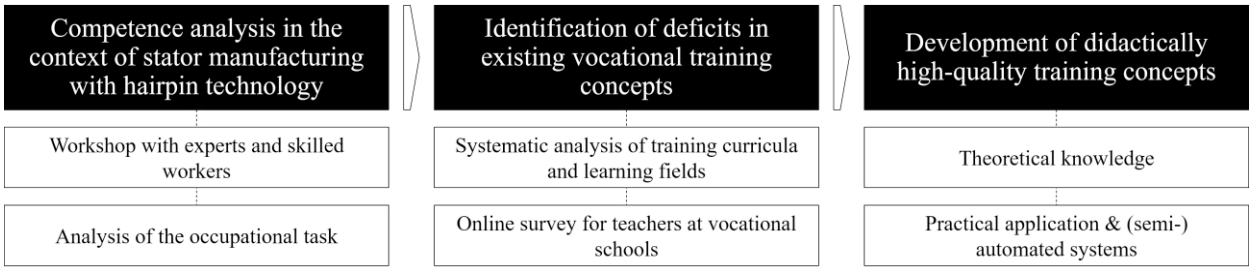


Fig. 2. Approach for deriving training concepts of high didactic quality in the context of stator production with hairpin technology.

specific deficits in the training content. Finally, a vocational training concept was developed using pedagogical methods in order to optimally counteract the determined deficits. Particular attention was paid to achieve an optimal mix of theoretical basics and practical applications which represents an optimal complement to the current curricula.

The determination of required working skills for stator manufacturing was conducted through an analysis of the process chain for stator production available at the wbk Institute of Production Science [11]. This competence analysis focused not only on the basic technical knowledge in detail, but also on deriving the so-called work process knowledge, which vocational education specifies as the combination of theoretical and practical knowledge [6]. Therefore, a workshop with experts and skilled workers, often used in vocational pedagogy to define occupational profiles, was initially held. It pursued the goal of systematically examining the entire process chain and of recording the work process knowledge as comprehensively as possible. For the identification of tangible work and learning contents, a work analysis of the hairpin process chain based on the analysis of the occupational task was carried out [12].

To identify deficits in vocational education and training, teachers at vocational schools were invited to an online survey based on the documented work process knowledge. The target group of the survey were, in particular, teachers who organize the interdisciplinary learning fields in vocational schools for technical occupations. In addition, a target system for the examination of curricula was created from the contents of the survey. To systematically examine the framework curricula a value-benefit analysis was conducted. The teaching contents of various vocational training programs were assessed and assigned to compliance levels according to consistency with the previously defined requirements. This allowed a more dependable identification, evaluation and clustering of target groups.

Building these results, pedagogical training concepts for several target groups such as apprentices, skilled workers, specialists and engineers as well as teachers and managers in the fields of electrical engineering, metal technology and automotive engineering were developed. In order to guarantee a solid didactic basis, the most important didactic models and state-of-research concepts were thoroughly analyzed and tested to the conceptual suitability in the context of the training factory. Especially, the concepts of action orientation and experience-based learning were identified as particularly promising and therefore taken into account for the development of training concepts [13].

## 4. Results of analysis and derived training concepts

Some of the results from both, the teachers' feedback on the online survey and the analysis of the framework curricula are shown in Fig. 3. The diagram illustrates the apprentices' expertise within selected relevant competences for the production of modern traction drives. It can be seen that they already have comprehensive knowledge in conventional and overarching fields such as machining operations, joining processes or material properties. These teaching contents are applicable in classical automotive production of the present as well as in future applications in electric mobility. However, in the case of more specific competences in stator production such as the bending and

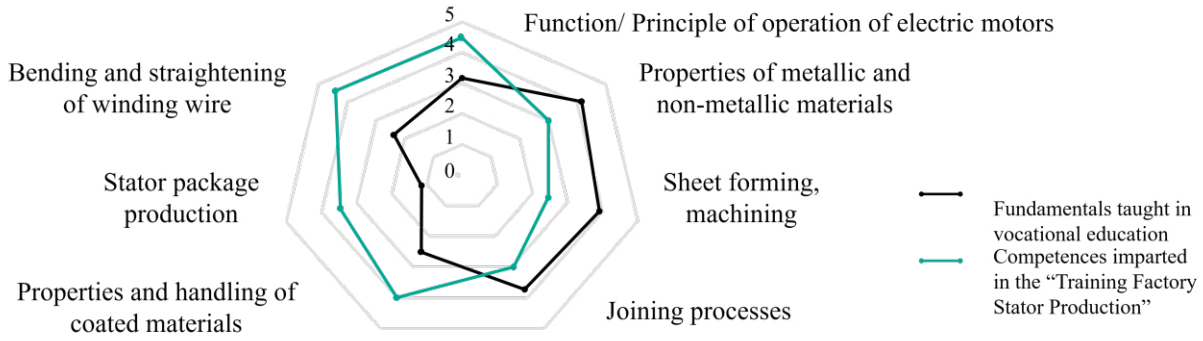


Fig. 3. Overview of competences for the production of stators with hairpin technology.

straightening of winding wire or the handling of coated materials, the framework curricula of the apprenticeship programs currently still show clear deficits. This is where the "Training Factory Stator Production" and its interdisciplinary training approach is to be applied as a supplementary concept. The broad fundamentals provided by vocational education and the specific and highly practical training concepts complement each other and contribute positively to the overall competences of the apprentices or skilled workers. The training should not be seen as an alternative to vocational education, but rather as aggregated training on the specific subject of electric motor production. Instead of extending the framework curricula by a further theoretical block, the additional training offers the opportunity to gain real insights into the future working environment in a practical workshop using state-of-the-art technology.

The training concepts for the "Training Factory Stator Production" were derived from the gathered work process knowledge and the identified deficits in existing vocational training. In order to promote the participants' decision-making skills, learning objectives were defined on the basis of technical, social, methodological and personnel competencies, and the individual working steps and contents were planned in detail, see Fig 4. Subsequently, suitable teaching and learning methods – the information sequence, the teaching discussion and the four-stage method – were determined taking into account the previously selected didactic concepts for practical orientation and experience-based learning for the following elaboration of the training contents. The selection of suitable media and materials as well as the planning of the time frame complement the training concept. Due to the restrictions in time of the training courses, it is neither scheduled nor feasible to check the learning progress as it is usually done [14]. For the training

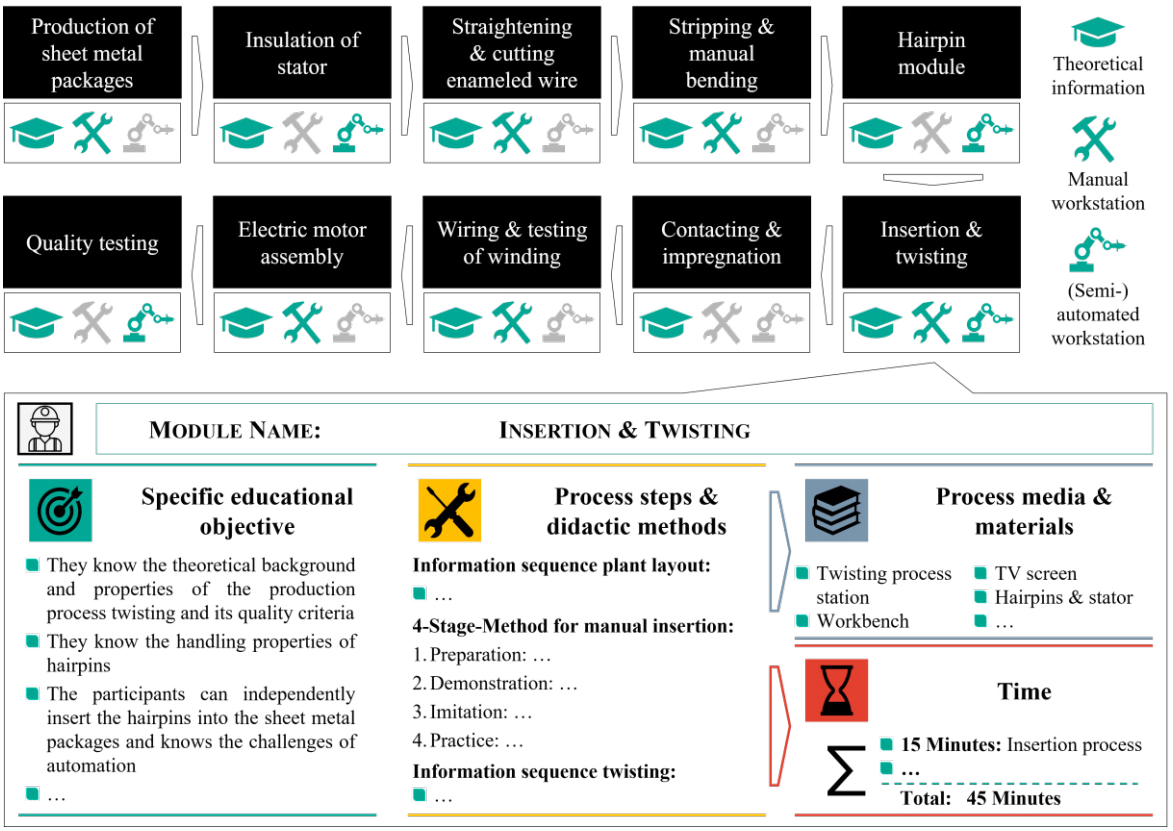


Fig. 4. Theoretical and practical modules of the "Training Factory Stator Production" and simplified example from the derived training concepts.

concepts' simple application and visualization, a well-structured tabular presentation with colored distinctions and symbols for the individual planning aspects of the training modules was developed.

In conclusion, the developed training concepts must be evaluated in a test phase and, if necessary, be revised before they are made available for training at the wbk Institute of Production Science.

## 5. Summary and outlook

The current transformation process of the automotive industry towards electric mobility entails new demands on product development and production technology, which require appropriate employee qualification. In order to provide small and medium-sized companies, particularly those affected by change, with the opportunity to train their employees, the wbk Institute of Production Science at the KIT has developed training concepts for manufacturing stators for electric traction motors using the hairpin technology. To this end, the theoretical and practical competencies required for stator production were first derived using pedagogical methods and then used as the basis for specific teacher surveys and literature-based analyses of the corresponding framework curricula for vocational training. On the basis of the identified deficits, training concepts of high didactic quality were developed according to recognized pedagogical approaches, which in particular address the qualification of trainees, but due to their modular structure also offer opportunities for training skilled workers, engineers and managers. Current works are implementing the training concepts and the actual "Training Factory Stator Production", which will subsequently be optimized in a test phase before made available for those interested in training at the wbk Institute of Production Science.

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