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Online engineering education for manufacturing technology: Is a remote experiment a suitable tool to teach competences for "Working 4.0"?

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Abstract

The demands of modern industry contexts (so-called Industry 4.0) are going to reshape the working world of future engineers. It seems obvious that these technological developments will affect higher education institutions with increasing intensity. For years, there has been a vivid discussion on the IT competences, which need to be developed by students in order to face emerging technology changes. To tackle the question regarding industry expectations towards future engineers, in this article a remote laboratory at a German university is analysed to identify potentials for future-oriented teaching and learning in the light of the required competences for "Working 4.0". Current scientific studies and industry agendas about Working 4.0 competences are identified, connected learning objectives are derived and the focused remote laboratory is linked to these objectives. As a result, it can be shown that this educational setting has the potential to reflect the complexity of Working 4.0. However, the results also show that the examined laboratory addresses only some of the competences in the context of Industry 4.0. Furthermore, it is argued in how far industry demands serve as the only basis for educational development efforts. The scientific studies and the industry agenda offer a limited and more political perspective on educational development. Nevertheless, based on the research in this article, it can be argued that remote labs (and online labs in general) have the potential to lift traditional laboratory-based engineering education to a modern engineering education 4.0.

1 | INTRODUCTION

The area of laboratory education research examines the theory and practice of teaching and learning in and with laboratories. In the last 150 years, practical hands-on work in laboratories has become an integral part of engineering education. In this context, carrying out experiments, evaluating measuring data and solving connected exercises have gained in importance in most of the research-oriented and applied degree programmes (May, 2017; Morace, May, Terkowsky, & Reynet, 2017). Especially in highly-industrialised countries, laboratory education will become even more important in the future, as technological changes and the ongoing digital transformation are expected to constantly change the world of work (Ruano-Borbalan, 2017a). Hence, engineering students must be prepared at a theoretical, empirical and practical level (acatech, 2016; Tekkaya et al., 2016).

1.1 | From Industry 4.0 to Working 4.0

The fourth industrial revolution is understood as the integration of the “Internet of Everything” (IoE) in industry, especially production processes (European Commission, 2019; Hermann, Pentek, & Otto, 2016). The “European” term “Industry 4.0”—and similar terms such as “Industrial Internet” or “Smart Manufacturing” used in other regions of the world—, describe a profound change in the manufacturing sector:

> Industry 4.0 can be understood as both a “political-economical” program to re-industrialize Europe but is also a “techno-logical” consequence of current developments in industry and science. Accordingly, production technology will interweave with information and communication technology to form intelligent networks of factories, machines, devices, materials, and workers which fulfils highly individualized customer demand in a highly responsive manner (Erol, 2016).

The basic principle of Industry 4.0 is an automated and digitally-networked industrial production and logistics chain to achieve production goals in a flexible, agile and highly efficient manner (European Commission, 2019; I-SCOOP, 2020). While on the one hand Industry 4.0 is seen to provide “immense opportunities for the realization of sustainable manufacturing” (Stock & Seliger, 2016), on the other, “more and more businesses see robots as means of maximising output, efficiency and profit and potentially displace human workers altogether. (…) Moreover, all workers will need to adapt, as their occupations evolve alongside increasingly capable machines. Some of that adaptation will require higher educational attainment” (Dastbaz, 2019).

The term “Working 4.0” builds on that discussion, but focuses on the forms and conditions of work (Spath & Bauer, 2012). Even though what the future world of work will look like is still an open question, the drivers and actors of innovation are under critical observation (Godin & Vinck, 2017; Ruano-Borbalan, 2017b). Nevertheless, it can be expected that 4.0 working environments will be more networked, digital and flexible, requiring a more academically skilled workforce (Kauffeld & Reining, 2019).

1.2 | Competence demand for Industry 4.0

For decades, there has been a discussion on the competences (understood according to the definition of the European Quality Framework for Lifelong Learning (EQF) (European Commission, 2008)) which students must develop in order to face the real-world challenges of engineering (Fritzsche & Oks, 2018). However, the ongoing digitalisation and smartification currently introduce challenges in the 4.0 work environments which cannot be clearly explained. This is both true and critical for the design of teaching and learning processes in laboratories (Terkowsky, Frye, & May, 2019). Whereas some modern industrial activities can be easily mirrored in online laboratories (e.g., working with digital equipment), others are more difficult to include (e.g., working in distributed but digitally connected teams). However, the authors consider that online laboratories offer potential for the development of adequate competences for the 4.0 work environment as a whole. In addition to new instruction technology, this also requires new learning approaches, formats and explicit content that are specifically related to Industry 4.0 (Stifterverband, 2016).

To this end, this study reviews a university's teaching and learning laboratory with respect to training in relevant competences for Industry 4.0 contexts and identifies untapped potentials for competence development for the 4.0 world of work. However, a remaining question is the legitimacy of connecting industry competence demand and the academic learning objective as a whole. Although, we are looking at the laboratory from the industry and the academia perspectives, there is not yet full agreement from both sides that this connection is a valid one. Although industry receives most of the engineering alumni, academia often argues that it is not the talent pipeline for companies. This is and will remain an ongoing discussion and will have an impact on research such as that presented in this article. Nonetheless, we will not discuss this point in depth, as it was not our focus for the study and as it demands a deeper discussion, possibly disconnected from an explicit case study such as the one presented here.

This article identifies the nexus between teaching and learning activities in the analysed remote laboratory and related learning objectives related to Working 4.0. At a meta-level, it elaborates overarching potentials for improving laboratory education and technical set-ups to foster design-based learning. However, it is necessary to define the roles and connections of industry and universities for a future-oriented economy.

2 | THEORETICAL BACKGROUND

2.1 | Manufacturing engineers' work

According to the European Commission, the manufacturing sector with 2 million companies and 33 million jobs is a strong economic factor in Europe and contributes 16% to the European gross domestic product (GDP) (European Commission, 2019). The term manufacturing describes and defines a variety of human activities, from handiwork to high tech, but is most usually applied to industrial design in which raw materials are transformed into finished goods on a large scale (Sahoo & Das, 2019). According to Sahoo and Das (2019), it is the most important area in any engineering process and manufacturing engineers have become key people in many organisations, providing extensive knowledge and competences in the fields of manufacturing and production technology. Their education normally takes place at universities and leads to bachelor, master and doctoral degrees (Morace et al., 2017).

2.2 | Working 4.0 at the threshold of higher education institutions

According to the results of a recent study on *Higher Education for the Working World 4.0* (Stifterverband, 2016), the digital transformation will change professions, products and modes of production. Hence, design competencies will become indispensable. Following the study's authors, this is mainly driven by the increasing digitalisation and the related elimination of routine activities. This means that:

- (industrial) work will become more complex and the qualification requirements for employees will become more demanding,

- research-based activities will permeate the world of work more strongly and adequate academic qualifications will become more and more relevant, and finally
- new job profiles will emerge, characterised by digitisation and human-machine-AI interaction.

The study concludes that, in order to successfully meet these challenges, working and learning with digital technologies must become an integral part of the academic competence profiles. However, the 4.0 work environment does not mean a fundamental replacement of previous educational goals for higher education, but their extension:

> With such an academic profile, the skills added to digital skills continue to form the basis for a scientific, career-oriented, and personality-building study. For the Working World 4.0, however, the relevance to application (due to the increasing integration of academic and professional competences) and the formation of personality (due to the new, cooperative forms of working) are becoming more important than before (Stifterverband, 2016).

Furthermore, new competence requirements in areas such as socio-technical collaboration, design thinking, self-organisation, creativity, innovation and entrepreneurial thinking will become key demands of future workers (Lemaître, 2018). This raises the question if and how far online labs have the potential to fulfil these needs for novel infrastructures to nurture these competences.

2.3 | The "cyber-physicalisation" of the laboratory in science and engineering education across one century

According to C. R. Mann, practical laboratory tutorials find their origin at the Massachusetts Institute of Technology (Mann, 1918). In 1869, E.C. Pickering implemented the first laboratory exercises as an extension of the established lectures and tutorials. During the next five decades, different usage scenarios for laboratory teaching were developed, e.g., as an illustrative supplement to the lecture, as a place to learn empirical research methods and methods of industrial production or to nurture the "spirit of research" in students (Mann, 1918).

Studies on the effectiveness of the laboratory in higher engineering education show that research-based learning can support the development of subject-related and interdisciplinary competences. However, most study materials are still based on traditional inductive-instructive laboratory methods. They are designed to be less supportive for innovation and to only marginally promote research-oriented learning required for successful work in Industry 4.0 (Tekkaya et al., 2016).

In addition, the digital transformation has far-reaching consequences for laboratory education formats. On the one hand, the progress of knowledge in the field of Industry 4.0 is increasingly the subject of research and teaching. On the other, its tools are increasingly penetrating research and education as media of mediation. This means that, in order to address the overarching competence objective of "dealing with digital requirements in the occupational field" both content-related and media-technical-structural adjustments are indispensable.

The interaction with cyber-physical experimentation facilities can take place locally or can be arbitrarily remote and remote-controlled using a web service. Moreover, computer-generated interactive simulations can replace the physically real laboratories and experiments. May (2017) lists the most common types of experiments and derives the following typology:

- pedagogical approach in use (demonstration, pre-structured experimentation, accompanied free experimentation or self-directed experimentation)
- type of interaction (human-machine interaction or human-computer interaction)
- type of experiment (real laboratory equipment or computer-generated simulations of equipment)
- whereabouts of experimenters and experiment (co-located in the same location or in different locations).

Furthermore, Zutin, Auer, Maier, and Niederstatter (2010) characterised the hybridisation of real and virtual experiments. Based on this, it is possible to distinguish educational laboratories according to their pedagogical approach and the degree of virtualisation into real laboratories (1), augmented reality labs (2), remote laboratories (3), and simulations of laboratories (4). As a third dimension, further distinctive features, such as international or locally-used laboratory application can be added, as shown in Figure 1.

In particular, the creation of the technical setting and the provision of support technologies in the context of hybrid and/or remote laboratories are crucial for research and development. Remote laboratories are usually controlled via Remote Laboratory Management Systems, providing functionalities such as user management, experimental data management, or interfaces for integration into Learning Content Management Systems (Zutin, 2018). For example, the scalability of remote laboratories for large numbers of users of Massive Open Online Labs (MOOLs) presents a particular challenge and is a current field of research and development in this area. The aim is to maximise the sharing of online labs and minimise or eliminate the waiting time for access (Salzmann, Halimi, Gillet, & Govaerts, 2018).

The following section outlines which competences in the area of Industry 4.0 are currently required in order to answer whether and to what extent online laboratories can promote the development of the necessary competences. We take into account the concept of "Constructive Alignment" (Biggs & Tang, 2011) which is an evaluation and a design approach for teaching and learning which has become increasingly used in higher education. Belonging to the outcome-based teaching and learning approaches, Constructive Alignment does not focus on what a teacher wants to teach, but on which outcomes a learner must achieve, based on the teacher's teaching activity and the resulting learner's learning activity (Biggs & Tang, 2011). In the language of Constructive Alignment, we analysed the "intended learning outcomes" (ILOs) of the selected laboratory in order to map out the learning objectives that the laboratory developers set themselves for the laboratory. Subsequently, we evaluated if these ILOs currently matched the possible learning goals (based on competences) of the Industry 4.0. We did this using a qualitative content analysis.

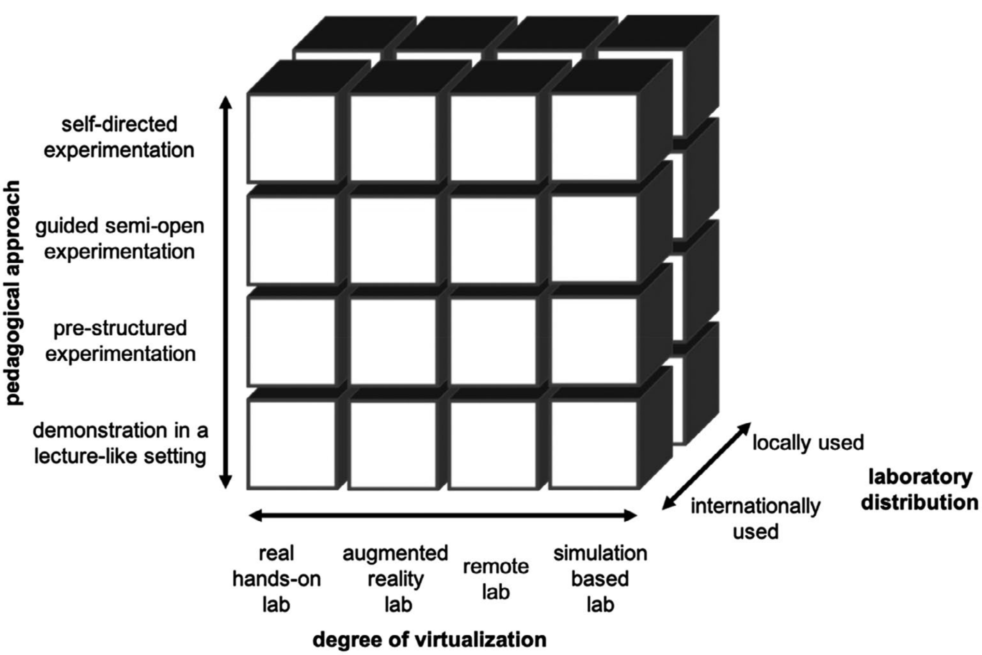

FIGURE 1 Three-dimensional framework for online laboratory differentiation (see May, 2017). *Source*: Authors

3 | CASE STUDY WITH A THREE-STEP COMPARATIVE QUALITATIVE CONTENT ANALYSIS

3.1 | Method applied

Content analyses are category-developing and category-led text analyses. Texts are systematically summarised and analysed, based on theory and rules. This is particularly suitable for investigating debates and literature (Mayring, 2015). We used this method for the following three steps (see Figure 2):

1. Analyse studies on Industry 4.0 competences in order to extract those which different stakeholders of an Industry 4.0-based economy expect. As a first result, derive an overall competence catalogue.
2. Analyse publications on the remote laboratory to extract explicitly- or implicitly-stat
3. ed learning objectives.
4. Compare the derived catalogue of the expected industry 4.0 competences: (1) with the identified learning objectives; (2) as an exemplary reality test, i.e., which competences are already addressed and what can be expected from higher education in future.

3.2 | Examined remote lab

The research activity presented in this article is designed as an analysis of the most important scientific papers of the "Tele-Operative Testing Cell" (Ortelt, Sadiki, Pleul, Becker, Chatti, & Tekkaya, 2014). This remote laboratory for material characterisation is part of the field of manufacturing engineering education for bachelor and master students at TU Dortmund University in Germany. It was developed by the Institute of Forming Technology and Lightweight Components (https://www.iul.eu/en/) during the two stages of the Excellent Teaching and Learning in Engineering Science (ELLI) collaborative project funded by the German Ministry for Research and Education between 2011 and 2020 (Frerich et al., 2016).

The laboratory focuses on the uniaxial tensile test which determines material parameters for forming technology (Macherauch & Zoch, 2014). Because of the strong forces that are necessary for this kind of material tests, certain hazards are associated with careless handling (Sadiki, Ortelt, Pleul, Becker, Chatti, & Tekkaya, 2015). Hence, a laboratory instructor must supervise the experiments to guarantee the safety of the students and prevent the damage of the machines. Because of this high level of supervision, students can conduct only one experiment, although the change of parameters of an experiment would enable them to create knowledge. Therefore, the Institute of Forming Technology and Lightweight Components at TU Dortmund University developed a remote laboratory (see Figure 3) to offer access to experiment time and an independent location (Terkowsky, Haertel, Ortelt, Radtke, & Tekkaya, 2016).

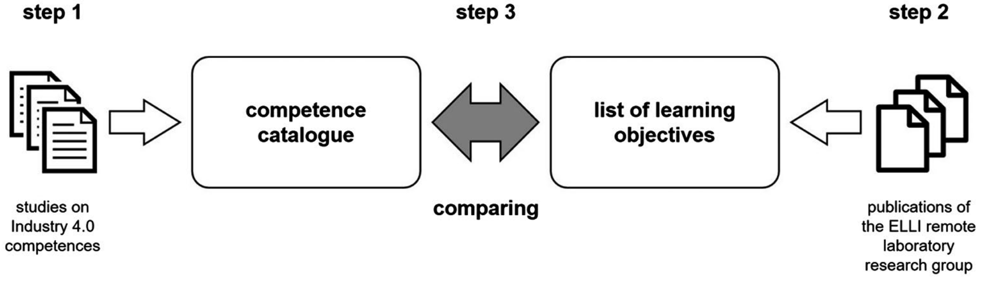

FIGURE 2 Schematic representation of the methodical procedure. *Source:* Authors

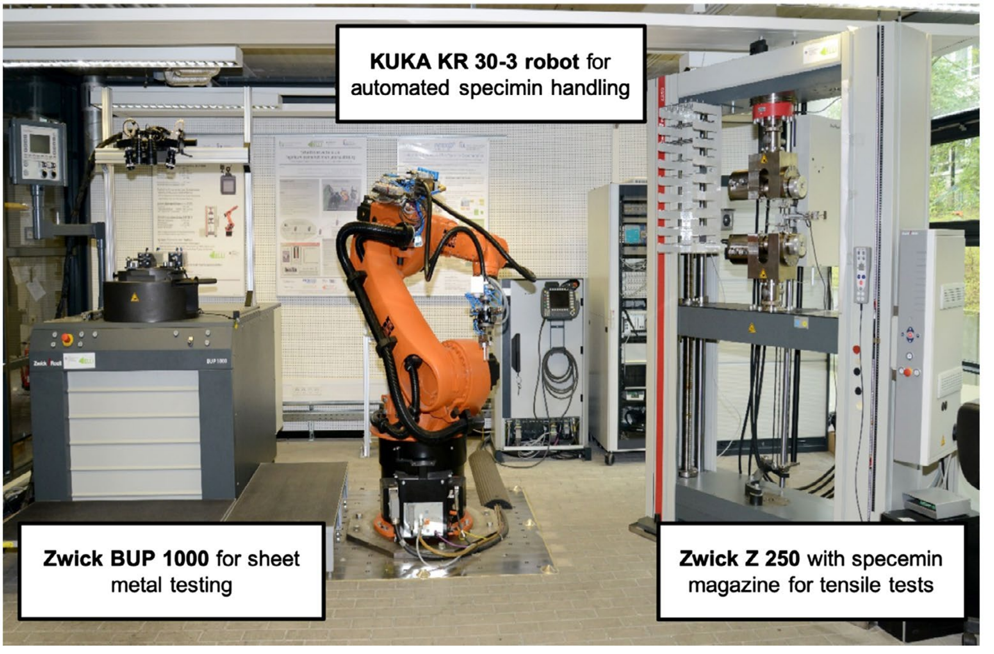

FIGURE 3 Testing cell for remote experimentation at Institute of Forming Technology and Lightweight Components (IUL). *Source:* Institute of Forming Technology and Lightweight Components, TU Dortmund [Colour figure can be viewed at wileyonlinelibrary.com]

Since they form part of the ELLI project, many publications are devoted to the contextual, technical, organisational and methodological design of the selected laboratory. In order to assess the origin of the texts, it should be noted that no article directly addressed the topic of Industry 4.0, but all focused on technical subjects or higher engineering education. A total of 15 publications of the ELLI remote laboratory research group was evaluated (Haertel, Terkowsky, May, & Pleul, 2013; May, Ortelt, & Tekkaya, 2015; May, Sadiki, Pleul, & Tekkaya, 2015; May, Terkowsky, Haertel, & Pleul, 2012, 2013; Meya et al., 2016; Ortelt et al., 2014; Ortelt, Pekasch, Lensing, Gueno, May, & Tekkaya, 2016; Pleul, 2016; Sadiki et al., 2015; Selvaggio, Sadiki, Ortelt, Meya, Becker, Chatti, & Tekkaya, 2016; Terkowsky & Haertel, 2013; Terkowsky et al., 2013; Terkowsky et al., 2014; Terkowsky, May, Haertel, & Pleul, 2013).

4 | RESULTS

4.1 | Industry 4.0 competences according to contemporary studies (step 1)

At present, there is no officially adopted and universally applicable standard of Industry 4.0 intended learning outcomes, neither at national nor at international level. However, several resources provide hints about expected future skills. They partly rely on in-house studies, mostly in the form of surveys with company representatives. Five current studies were analysed (acatech, 2016; Hermann et al., 2016; Pfeiffer, Lee, Zirnig, & Suphan, 2016; Schlund & Pokorni, 2016; Stifterverband, 2016).

The summary of the relevant competences is based on the framework model of the EQF (European Commission, 2008). The structuring grid differentiates between three main competence clusters:

1. subject-specific and interdisciplinary technical competences (with regard to concrete technologies and organisational structures),

2. social competences (with regard to social interaction structures) and
3. self-competences (with regard to individual personality structures)

4.2 | Derived structuring catalogue of Industry 4.0 competences

Based on the content analysis of the listed studies, a model of 18 competences, which are of particular relevance for the context of Industry 4.0, could be carved out:

4.2.1 | Subject-specific and interdisciplinary technical competences for Industry 4.0

In the context of subject-specific and interdisciplinary technical competences, learners should be able to meet the requirements of Industry 4.0. These are:

1. to think, act and collaborate in interdisciplinary contexts
2. to flexibly adapt business processes to new technologies such as additive manufacturing or augmentation
3. to design IT processes in the context of production and to use IT components for human-machine interaction
4. to design and control holistic and complex production processes and networked production structures, as well as to manage appropriate interfaces (including the implementation of problem-solving and optimisation processes)
5. to establish a connection between a digital twin and its physical reality
6. to deal with large amounts of data and use appropriate statistical skills (including recognising the importance of algorithms and the management of sensitive data)
7. to demonstrate system competences by recognising functional elements, identifying system boundaries and making predictions about system behaviour
8. to initiate and implement innovation processes
9. to control the legal context of the entrepreneurial act
10. to think or act strategically in a company-specific way and use the appropriate evaluation tools in complex decision-making situations

4.2.2 | Social competences for Industry 4.0

In the context of social competences, learners should be able to meet the requirements of Industry 4.0. These are:

11. to communicate business fluently and cooperate both internally (in terms of process flows) and externally (in terms of customers and supplier relations)
12. to act confidently and effectively in social (including intercultural) contexts
13. to lead production units and teams in a goal-oriented way
14. to design digitally-supported interaction and cooperation processes

4.2.3 | Self-competences for Industry 4.0

In the context of self-competences, learners should be able to meet the requirements of Industry 4.0. These are:

15. to realistically assess the value of one's subjective knowledge of experience and incorporate it accordingly in one's action
16. to think and act with self-determination and organisation

17. to act upon one's own open-mindedness and creativity
18. to design and implement one's own lifelong learning

In order to analyse if the promotion of these Industry 4.0 competences are addressed in the existing laboratory concept, we examined the 15 above-mentioned publications on the TU Dortmund remote laboratory.

4.3 | Learning objectives in the analysed laboratory (step 2)

According to Mayring (2015), the qualitative content analysis is chosen to identify learning objectives or intended learning outcomes that are explicitly or implicitly stated in the analysed publications of the ELLI remote laboratory research. Statements about the laboratory's intended learning outcomes or learning objectives were found in eight of the 15 analysed texts. A total of 29 relevant content-bearing passages could be identified and paraphrased. After an initial reduction, 23 learning objectives of the laboratory were coded. The coding shows that the identified learning objectives could be divided into four groups:

Four codes correspond to the objective to **gain practical experience** in the use of technical equipment in general and laboratory equipment in particular: showing practical experience with technical equipment (1), showing general technical competences (2), showing technical understanding of the process (3), and considering independence in place and time (4).

Six codes belong to the objective that students **plan, carry out and reflect experiments**: planning the tele-operative experiment (5), planning the on-site experiment (6), carrying out the tele-operative experiment (7), carrying out the on-site experiment (8), linking theory and practice (9), showing experience in experimental procedures (10).

Five codes refer to the technically-correct **gathering and evaluation of measured data and characteristic values**: calculating material specific values (11), representing data with graphics and evaluating measured data (12), assessing the suitability of materials (13), classifying and using technical data (14), communicating/ presenting findings, procedures and results (15).

Eight codes refer to the general acquisition of "**problem-solving abilities**": showing creativity (16), learning in a self-directed and self-organised manner (17), learning from failure (18), thinking in an open-minded way about new solutions (19), developing an adequate work schedule (20), acting with adequate timing and organisation (21), acting in a self-reflective manner (22), and working in an autonomous manner (23).

4.4 | Comparing Industry 4.0 competences and laboratory learning objectives (step 3)

The last step was to check whether the learning objectives (or the respective codes) could be assigned to the identified 18 required Industry 4.0 competences (see Figure 4).

In total, it was possible to allocate 14 of the 23 learning objectives. (In the following, the identified text passages are shown in italics. Meaningful keywords are highlighted in bold.) Considering the frequency of the different learning objectives, it is remarkable that the competence "to think and act with self-determination and organization" (No. 16, "self-competences" cluster) is referred to seven times. An example is: *"Hence, the students have to* ***develop a working plan in their group*** *when to do the experimentation and arrange the experimentation by booking a time slot"* (May, Ortelt, & Tekkaya, 2015); another is: *"So students could learn about superposition of stresses* ***by themselves room*** [sic*!]* ***and time independent"*** (Meya et al., 2016).

The competence "to communicate business fluently and to cooperate, both internally and externally" (No. 11, "social competences" cluster) is addressed six times. An example (learning objective communicating/presenting findings, procedures and results) is: *After completion of the laboratory, students should be able [...]* ***to present*** *scientifically and in line with the target audience the experiments, the* ***procedure*** *and the* ***results*** *in a laboratory report, and to be able* ***to defend their findings in a scientific discussion*** (Pleul, 2016).

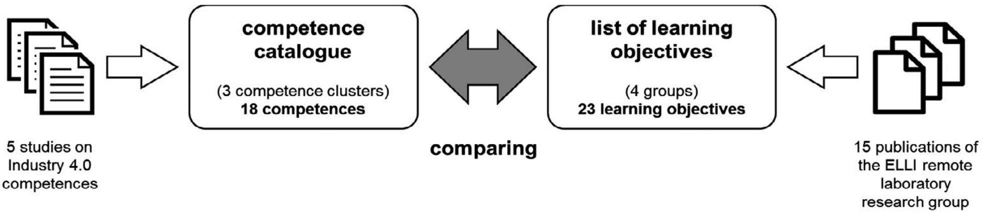

FIGURE 4 Schematic representation of the methodical procedure for the exemplary case analysis. *Source*: Authors

When comparing the competences that are already addressed by formulated learning objectives, it is seen, that, in total, all four competences of the "self-competences" cluster and three out of four competences of the social competences cluster are addressed. However, only two of the ten technical competences were addressed by the learning objective. An example is "showing technical understanding of the process", which is assigned to the competence "to demonstrate system competences by recognizing functional elements, identifying system boundaries and making predictions about system behaviour" (No. 7, "subject-specific and interdisciplinary technical competences" cluster): *"After finishing the laboratory course, students should be able to [...] **describe the problem regarding the requirements for the production** of a set radius with the principles of forming technology **on the basis of the observed forming process and to analyse based on their previous knowledge** and to develop hypotheses"* (Pleul, 2016).

The same counts for "planning the tele-operative experiment" and "carrying out the tele-operative experiment" learning objectives, which can be assigned to the "to design IT processes in the context of production and to use IT components for human-machine interaction" (No. 3, "subject-specific and interdisciplinary technical competences" cluster): *"They are asked to work on this problem in small groups by planning and carrying out experiments **using the tele-operated equipment**"* (May, Terkowsky, Haertel, & Pleul, 2012).

5 | DISCUSSION

In our study, we analysed the ILOs of the selected laboratory in order to map out the educational goals which the laboratory developers set themselves. Subsequently, we evaluated to what extent these ILOs currently matched Industry 4.0 competences. It is possible to map out several peculiarities.

Concerning the initial educational goals of the laboratory, it can be stated that the four groups of learning objectives are in line with classic taxonomies of ILOs for the educational laboratory. According to an empirical study on ILOs in the engineering laboratory (Tekkaya et al., 2016) these four groups are among the most widely used in manufacturing technology.

Moreover, in the context of Working 4.0, a variety of explicit and implicit learning objectives could be identified which directly address the formulated competence requirements. In particular, the social and self-competences clusters are addressed. This heavily relies on the explicit didactical and methodological design of the analysed laboratory which follows the model of experiential learning. It allows for students' creativity, promotes learning from mistakes and encourages self-organisation in the learning process. For example, it supports the development of students' self-competence, as required in the context of Working 4.0.

The technical design of the laboratory shows the influence of the remote laboratory. This concept brings "something digital" into the laboratory which is essential in terms of the 4.0 work environment. However, the results also show that only a few technical Industry 4.0 competences are addressed in this particular laboratory. The unavoidable systematic approach in the sense of the "one right way" in the implementation and evaluation of the experiment offers hardly any possibilities for "innovations" on the part of the students. The limited subject-specific design limits the promotion of interdisciplinary thinking and acting. This also implies the absence of upstream and downstream processes to map holistic structures, interfaces and complex decision-making situations. Based on that, it is possible to derive recommendations with regard to competence orientation in the context of Working 4.0:

1. It is essential to design or embed the laboratory in a cross-disciplinary context.
2. Connecting with other laboratories under a common, wider problem can initiate a more comprehensive teaching-learning scenario.
3. If the given problem is less aligned to subject-specific basic knowledge, but more to the practical context, this can foster the ability to operate in complex and networked structures.

Finally, it should be mentioned that nine coded objectives of the considered laboratory could not be assigned to the competences in the context of Working 4.0. They refer in particular to the “classical academic educational objectives” (Stifterverband, 2016) of engineering education. However, in the context of this laboratory, these objectives do not hinder the acquisition of the required Working 4.0 competences. This shows that the training of engineers for an Industry 4.0 does not mean that only “new” competence requirements are relevant. They do not replace the previous educational objectives but complement them and further develop them for increasingly digitised and networked systems and processes.

Looking at the results, however, the reader needs to be aware of the fact that the analysed contemporary studies on Industry 4.0 competences mainly represent the industry perspective and its hidden attempt to make little use of the higher education system for its own vocational education purposes and for advancing its own competitive industrial development. In contrast to that, higher education also needs to be based on broader educational goals instead of simply adapting to new technical, economic and organisational goals of the industry. Topics like environmental and societal sustainability need to be addressed with the same priority as industrial changes and demands. Hence, the papers we analysed and used for this study do not show the whole picture. They neither represent critical perspectives of other stakeholders in the socioeconomic system (e.g., trade unions, employee representatives, social organisations, working psychologists) nor include any other possible perspective of (non-)government organisations or academic critical sciences and technology studies. This is because we did not find any related resources suggesting and critically discussing intended learning outcomes for Industry 4.0 from such perspectives, even if we see these as highly important to display and understand the bigger picture. “However, at the dawn of Industry 4.0 and the common excitement about the potential rise of European industry it seems that sustainability, as an important and highly interrelated goal of European policy makers has been lost out of sight” (Erol, 2016).

Ultimately, for the higher engineering education “shop floor” and from the perspective of reflected didactic designing, the establishing of appropriately matched economic, environmental and societal intended learning outcomes to foster the acquisition of holistic sustainability competences is something that all relevant stakeholders should consider if they want to influence the making of future engineers.

6 | CONCLUSION AND OUTLOOK

This article provides an overview of teaching and learning in the manufacturing technology laboratory in the context of the requirements of Working 4.0 and condenses the anticipated Industry 4.0-related competences of future engineers. As a way to promote these competences in the course of studies, the cyber-physicalised laboratory was introduced by explaining the general idea and an explicit example. By using content analyses, the case study analysed to what extent the design of the laboratory already addresses the competences required in the context of Working 4.0. It could be shown that this setting has the potential to consider the complexity of Working 4.0 and “digitisation” in form of a remote laboratory, which opens up a multitude of possibilities.

Finally, to analyse and reflect on intended learning outcomes are only one part of the didactic design using the Constructive Alignment approach. Further research should also take the learning activities and assessment into account.

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