Didactic Design of a Remote Collaborative Robotics Laboratory

Louis Kobras; Bernhard Meussen; Marcus Soll

2023 IEEE 2nd German Education Conference (GECon), 2023

IEEE Xplore: https://ieeexplore.ieee.org/document/10295126

DOI: 10.1109/GECon58119.2023.10295126

Didactic Design of a Remote Collaborative Robotics Laboratory

Louis Kobras, Bernhard Meussen, Marcus Soll
NORDAKADEMIE gAG Hochschule der Wirtschaft
25337 Elmshorn, Germany
{louis.kobras, bernhard.meussen, marcus.soll}@nordakademie.de

***Abstract*—Remote laboratories are a useful mean to improve access of students to laboratory infrastructure. This paper describes the steps taken in designing and implementing a educational laboratory for teaching collaborative robotics technology. First, background knowledge about collaborative robotics, didactic characteristics of laboratory education, as well as competence based teaching and learning is presented. Next, learning outcomes based on Bloom and technical requirements are determined. After that, principles in our laboratory design are laid out. Finally, A small trial run of a Master's course adhering to the concepts and principles laid out herein is presented. The course concept is intended for application in engineering and CS curricula. A first non-course-specific evaluation shows promising results; a large scale evaluation of the laboratory is currently in it's design phase and will be conducted in winter 2023.**

***Index Terms*—Curriculum development, laboratory education, learning outcomes, STEM education, higher education**

I. Introduction

Digitization is a mega trend which is meant to revolutionize many aspects of industrial processes [1]. Cyber-physical systems are the technical means to facilitate new products and improve processes in this context [2]. The ability to use the above-mentioned technology is a key competence of industrial engineers [3]. The use of laboratories in higher education has long been a crucial element to teach students natural sciences and engineering [4]. Using digitization technologies to improve the use of laboratories and to be the object of laboratory experience therefore is a promising field [5].

The work presented here develops a didactic design of a laboratory on a typical cyber-physical object, a collaborative robot. It furthermore benefits from the digital infrastructure of CrossLabs; a didactical, technical, and organizational framework for open digital lab objects [5]. The work follows the problem-solving cycle of the systems engineering approach [6, ch. 3]: in a situation analysis, the relevant aspects of the technology of collaborative robotics, the didactic characteristics of such laboratories and the setting in the education of industrial engineers are presented. On this basis, the aim of the didactic design of the laboratory is formulated. Methods to achieve the required learning outcomes are chosen and in the synthesis the design of a cyber-physical laboratory using collaborative robots is presented.

This research was part of the project *Flexibel kombinierbare Cross-Reality Labore in der Hochschullehre: zukunftsfähige Kompetenzentwicklung für ein Lernen und Arbeiten 4.0* (CrossLab), which is funded by the *Stiftung Innovation in der Hochschullehre*, Germany.

II. Related Work and Scientific Background

This section is structured as follows: First, in II-A, general knowledge about collaborative robots is presented. II-B follows up with the didactical aspects of laboratory education. II-C concludes with introducing the reader to learning outcomes from the Bloom school of thought as a base model for the didactical design of our laboratory.

A. Collaborative Robotics

Industrial robots are automated, freely programmable multi-purpose manipulators. They have at least three programmable axes of motion and are used in the automation of processes. These robots may be stationary or movable [7]. The robots are, depending on their specifications, able to manipulate high loads with high accelerations and velocities. Thus, robots are potentially dangerous due to the high kinetic energy in their movement. The installation and safe operation of robots require a risk assessment. Three modes of operation are defined [7]:

- automatic mode, where the control mechanism operates the robot according to the user program,
- manual mode, where the robot is directed by an operator, and
- collaborative mode, where a specifically designed robot within a defined workspace operates with a human user.

The specifically designed collaborative robots often use force detection combined with low speeds and low loads to avoid injury of human users in contact [8]. Collaborative robots are a good example of a cyber-physical system, following the definition in [2]: they consist of mechanical and electrical components (mechatronics), use embedded systems (hardware and software), have sensors and actuators and are network ready.

Collaborative robots (CoBots) are often used as a low-threshold automation technology in industrial processes. The cost for their application is typical lower than that of classical industrial robots due to the low price of collaborative robots and the missing safety fences or other safety measures. If their disadvantage of low speed and low loads is not important, for example when automating manual human processes, they are a widespread automation solution [9]. A typical collaborative robot is a six-axes-mechanism, which gives the robot the comparable kinematics to that of a human arm. The industrial

TABLE I
BLOOM'S TAXONOMY LEVELS AS DESCRIBED BY KENNEDY ([15])

Label	Meaning	Keywords
1. Knowledge	recall facts without understanding them	describe, state, name, recall, ...
2. Comprehension	understand / interpret learned information	classify, discuss, interpret, review, ...
3. Application	use learned material in new situations	assess, develop, modify, operate, ...
4. Analysis	break down information in its components	contrast, determine, identify, relate, ...
5. Synthesis	put parts together	arrange, compile, construct, set up, ...
6. Evaluation	judge value of material for given purpose	justify, compare, validate, interpret, ...

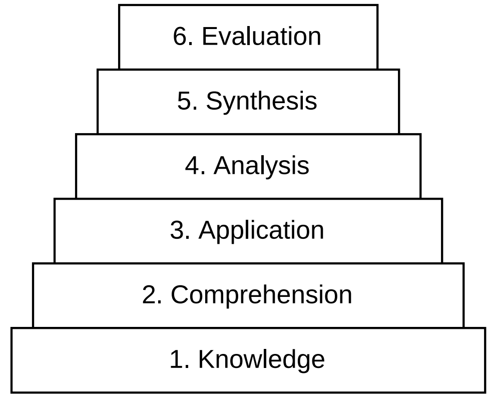

Fig. 1. Hierarchical Competence Taxonomy. Image based on [15]

application of a collaborative robot thus requires the proof of functionality, product safety and cost effectiveness [9].

B. Didactic Characteristics of Laboratories

The use of laboratories in the education of natural scientists and engineers has a long and successful tradition [4]. Laboratories in this context here are defined as an infrastructure which facilitates research and the application of theoretical knowledge in a practical teaching and learning environment. Following [10], 13 fundamental learning outcomes of engineering instructional laboratories may be derived: *instrumentation*, *models*, *experiment*, *data analysis*, *design*, *learn from failure*, *creativity*, *psychomotor*, *safety*, *communication*, *teamwork*, *ethics in the laboratory*, and *sensory awareness*. To cope with the trend of digitization and the use of cyber-physical systems, this set of outcomes may be extended further by the following outcomes: *know industry environment*, *overview over larger context*, and *working mindset / soft skills* [11] as well as *develop personality*, *improve style of learning and working mindset*, *develop critical thinking and acting sustainably*, *thinking out of the box*, *develop self-directed learning skills*, and *work with cyber-physical systems* [12].

C. Competence Levels in the Bloom Taxonomy

Bloom [13] describes a taxonomy of competence levels for competence oriented teaching and learning. Several revisions exist (e.g., [14], [15]); this work will use the taxonomy as described in [15]. According to this taxonomy for competence oriented teaching and learning, each competence may be assigned to one of six levels. These levels are described in Table I. Certain keywords may be associated with each competence and can be used as indicator as to the desired competence level. Note that some keywords may be associated with several levels, such as *select* for both *Comprehension* and *Application* [15, Sec. 3.2].

The competence levels are usually depicted in a hierarchical manner, with higher levels building upon lower levels. A "taxonomy pyramid" similar to the one used in [15] is depicted in Figure 1.

III. THE ROAD TO DESIGNING A COBOT LAB

This section pertains to the different aspects that need to be considered when designing a laboratoy. Sec. III-A derives the Learning Outcomes we defined for the lab unit which are matched to the Bloom levels of competence (as presented earlier). Sec. III-B discusses the translation of a lab concept to a lab unit implementation. In Sec. III-C technical requirements and specifications for a CoBot laboratory setting are presented. Finally, in Sec. III-D a proof-of-concept lab implementation scenario in the context of a Master's course is presented.

A. Learning Outcomes of a CoBot Laboratory for Industrial Engineers

Industrial engineers (German: "Wirtschaftsingenieure") are professionals integrating engineering and business management knowledge. Industrial engineers usually work on the interface of technical and economic processes in the production industry [3]. Among others, typical tasks for industrial engineers are the technological and economical feasibility decision on investing in automation technology and its application in the factory. As the use of the cyber-physical system 'collaborative robot' uses state of the art technology in automation, the knowledge of and the ability to implement this type of technology is an important professional asset for industrial engineers.

In addition to the learning outcomes listed in Section II-B, an internal discussion with a lecturer, an engineer experienced in the use of robots and higher education didactics and 5 master students in industrial engineering was used to derive the learning outcomes for a remote CoBot laboratory. Applying the competence levels as described in Section II-C, we define the following list of learning outcomes for:

1. **Knowledge**
   1) identify stakeholders
2. **Comprehension**
   2) explain the basic kinematic and kinetic modelling of the robot
   3) explain forces required to trigger the collaborative safety functions

3. **Application**
   4) program a collaborative robot to automate simple tasks
   5) use the motion control
   6) acquire process data
   7) solve design problems when automating processes
   8) solve the automation problem with incomplete information
   9) use creative methods in problem solving
   10) mount the robot and its required peripherals physically
   11) perform risk analysis
   12) perform requirement analysis
   13) work as a team in the automation project
4. **Analysis**
   14) analyse process data
   15) analyse errors and malfunctions for probable causes
   16) determine the quality of the automated process
5. **Synthesis**
   17) use robot to automate processes (in a larger context)
   18) propose solutions for errors and malfunctions
   19) establish safe environment
   20) set up automation project
6. **Evaluation**
   21) evaluate process data
   22) assess economic feasibility for a given problem
   23) consider and evaluate the consequences of the automation project

If we take a look on the learning outcomes as a whole, we can observe some interesting facts. First, the number of learning outcomes in the lower levels 1. Knowledge and 2. Comprehension is low. The reason for this is that students learn the basic knowledge of automation and robotics in prior courses so our course can focus on the specifics of applying CoBots to automation tasks. Second, while most learning outcomes are in 3. Application, we aim to also include higher competence levels, thus a number of learning outcomes can be found in each level.

B. Translating Learning Outcomes into Course Design

Based on the situation analysis presented above, it is the aim to design a laboratory setting that

- uses collaborative robots as an example for a cyber-physical system,
- to solves automation problems in the production of machinery, and
- to teaches students of natural and engineering sciences the practical use of digitization in the optimization of industrial processes.
- The setting shall give the students the experience to transfer simulated procedures into physical reality.
- The setting shall facilitate remote and on-site use of the laboratory equipment.
- The usage of the laboratory must be safe [8].

Starting point of the design of the didactics of the collaborative robotics laboratory are the learning outcomes, see above. Following [16], the didactic design of a teaching-learning-course consists of the design of the material to teach the content to the students, the design of tasks to activate the student's learning processes and the design of the learning circumstances to guide the students and to ensure communication.

Doing that, constructive alignment [17] will be used to focus on the learner's perspective. The learning outcomes, the teaching activities and the examinations are matched accordingly.

To match formal requirements of universities, the usage of laboratories is divided into the steps *safety instructions*, *operation instruction for the equipment used*, *preparation of experiment*, *experiment execution*, *documentation of results*, and *examination* [18].

C. Specification of the Technical Infrastructure for the Remote CoBot Laboratory

Based on the learning outcomes and the type of studies described in chapter Section III-A and the didactic design presented in chapter Section III-D, the following characteristics for the digital infrastructure for a remote collaborative robotics laboratory are specified:

- The collaborative robot should use force detection as the safety function.
- The robot controller must accept remote control.
- The workplace of the collaborative robot must allow the realization of the automation problem's solution.
- A remote programming tool is required.
- A remote simulation tool is desirable.
- The students must be able to book time to use the collaborative robotic laboratory.
- The physical robot must be able run the program with the remote student watching the robot's performance.
- The performance of the robot must be documented.
- The setting must ensure safe operation of the robot.
- On-site usage of the robot setting by the students must be possible.

If the problems given to the students are highly standardized, the workplace of the robot may be equipped with standard equipment and no individual preparation of the workplace is required. Individual automation problems require a specific preparation of the robot's workplace. The laboratory's staff or the students must carry out these preparations. The decision to use standardized automation problems or individual automation problems must be taken by the lecturer depending on the required learning outcomes and taxonomy.

The currently intended collaborative robotics laboratory workplace is shown in Figure 2. We use a Universal Robots UR5e[1] in combination with a Wrist Camera and different gripper technologies from Robotiq[2] to realise different palletizing and pick&place-scenarios. Students may either work directly with the teaching pendant attached to the robot (see

[1]https://www.universal-robots.com/products/ur5-robot/, 2023-07-07
[2]https://robotiq.com/, 2023-07-07

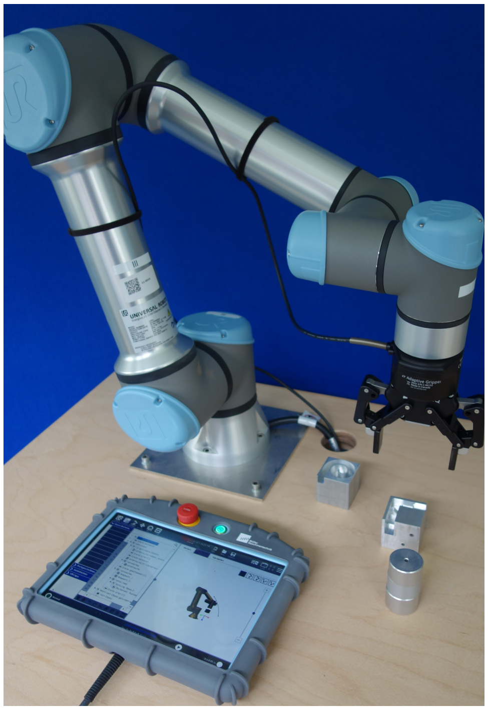

Fig. 2. Workstation of the CoBot, which is ready to grip the items laid out on the table. The tablet is used to program the CoBot.

figure) or remotely, currently using the software ArtiMinds RPS[3] and providing a webcam stream. Another remote control solution using the CrossLab architecture [5] is currently in development.

D. Design of the CoBot Laboratory

As the CoBot itself is considered partly completed machinery [19], extension to other machinery or equipment, such as a gripper and a CNC mill, is required for it to be able to serve a useful purpose.

To fulfil safety regulations, a risk assessment of the workplace in the laboratory must be performed. The results of the risk assessment might lead to safety procedures that have to be considered in remote and on-site operation. The necessary precautions of the laboratory's user must be derived from the risk assessment. The user must comply to these safety instructions. The safety instructions may be presented in written, as a video or in a presentation by the lecturer. The user must confirm that he has understood and will follow the instructions.

In the next step, the basic knowledge on industrial robotics is taught. This includes the definition of robotics, the knowledge of the types of robots, and their application. The components of a robot (manipulator, end effector, controller, peripheral equipment, surroundings) are presented. The basic control modes (direct and inverse kinematics and kinetics) will be explained. The definition of collaboration [8] and its technical implementation are discussed. This section gives the students the basic ability to locate the collaborative robotic technology in the framework of their own knowledge. The section may be presented as a lecture, in presence, in a webinar, in a video or in text form.

The operation and programming of the collaborative robot and its end effector is also part of the knowledge transfer process. As the robot is controlled by a graphical user interface (see Figure 2), this may be supported by interactive tools. Some suppliers of CoBots provide interactive learning tools for usage of the CoBot[4].

To train the ability to operate and program the collaborative robot, the students shall perform prepared tasks. This might be done either in a simulation of the controller in a virtual machine, in a robot simulation application, or remotely or onsite with the collaborative robot.

In this example, the robot picks up the product from one conveyor belt and, following a quality inspection, puts it on the second conveyor belt or in the bin. The student must program the robot to perform the required movements.

With the knowledge and the experience gained so far, the students either look for an automation task for themselves or choose a given scenario. These scenarios might be for example:

- The automation of a milling process: loading the milling machine with the raw material, starting the NC-program of the milling machine, and unloading of the finished product from the milling machine.
- The automation of an electric circuit quality control procedure: putting the electric circuit in the test unit of using a test device to directly contact the circuit, starting the test program, transporting the circuit to the 'good' or 'not good' station.
- The automation of the screwing of machinery: putting the parts into place, place the screws, tighten the screws, unload the mounted parts.

Depending on the setting and the scenario chosen, the project may be worked on as a group of students. If working in a group, the role and tasks of each student must be defined to ensure a just grading of the individual student's performance.

The students set up a concept for the solution of the automation problem following the problem-solving cycle [6, Ch. 3]. The students must identify which additional equipment is required. Depending on the possibilities at hand and the required taxonomy, the additional equipment is either prefabricated, so that the students only need to choose from a given set of equipment, or the equipment must be designed and prepared by the students. To ensure safety, a risk assessment satisfying [19] is required. The students look for risks using appropriate methods, document the identified risks and derive risk minimizing measures.

With the equipment and the automation concept, the students check the economic feasibility of the use of the col-

[3] https://www.artiminds.com/robotics-software-and-services/robot-programming-suite-basic/, 2023-07-07

[4] e.g., https://academy.universal-robots.com/free-e-learning/e-series-e-learning/, accessed 2023-04-12

laborative robot. They calculate the costs and check for the amortization of the automation solution.

As the planning of the automation solution is finished, the students set up the physical solution in the collaborative robotic laboratory. The programming of the robot must be done offline. Depending on the remote infrastructure and the taxonomy intended to reach, different settings are possible:

- offline programming of the robot by writing code,
- offline programming by using the controller software of the collaborative robot in a virtual machine or
- offline programming using a robot programming and simulation software.

If the required peripheral equipment is specifically prepared, the setting up of the robot and the equipment must be done by the laboratory's staff or the students on site. If a standardized solution has been chosen, this step requires less efforts or might even be obsolete. The realisation of the automation solution is either done on site or may be started remotely, for example as part of a experiment microservice setup using the CrossLab infrastructure [20]. The students' examination of the laboratory requires the following artefacts:

- a specification of the automation problem
- a concept of the automation solution
- a risk assessment of the automation solution
- a calculation proving the economic feasibility
- a program for the collaborative robot and its peripherals
- a proof of successful performance of the automation solution against the specification and the calculation

IV. Trial Run of the CoBot Laboratory

A trial course was executed that adhered to the principles laid out in this paper. The collaborative robotics laboratory was an undergraduate course in industrial engineering studies. Table II gives the timetable. The first five events were held online using video conferencing software. Using virtual machines, the students had online access to an offline simulator of the robot controller provided by the manufacturer and the robot simulation software in the first online phase and throughout the course.

At the end of the online phase, the students were able to choose from given problems (see above) or propose their own automation task. The course consisted of three teams, one with three students, two with four students. Two groups chose given problems; one group defined a problem on their own.

In the next step, the students defined the automation problem and set up a project structure. On this basis, the lecturer accepted the problem as the examination subject. This step served as the problem clarification step in the problem-solving cycle.

Following this cycle, the students derived a concept to solve the automation problem using methods like brainstorming, a morphological box and utility analysis. Missing equipment could be designed and manufactured, for example using a 3D printer.

The automation solution is then simulated using the controller software of the collaborative robot in a virtual machine or by using a robot simulation and programming software like ArtiMminds RPS. The program for the robot is then transferred to the physical robot and the program is tested in the physical environment. If necessary, the robot program is modified according to the findings.

TABLE II
Timetable of the trial course

Date	Agenda
02.08. (online)	• Introduction to the CoBot lab • Introduction to robotics • Installation of offline simulator
09.08. (online)	• Safety of CoBots • Robot controller software
23.08. (online)	• Design of CoBots • Robot simulation software, part 1
25.08. (online)	• Application of CoBots • Robot simulation software, part 2
30.08. (online)	• Economic aspects of CoBots • Robot simulation software, part 3
06.09. (on-site)	• Safety instructions • Introduction to the CoBot and its equipment
13.09.; 20.09.; 27.09. (on-site)	• Free work in the laboratory, guided by the lecturer • Realization of the automation problem

The students performed a safety analysis and checked for possible risks and documented the analysis with a failure mode and effects analysis. With the process data, the students checked their calculation for the amortization time and discussed the consequences of the automation project for the identified stakeholders. The grades were given on the criteria mentioned above. The results were very positive (93% in average).

We ran our normal, non-course-specific evaluation for university quality assessment on the course. Five out of eleven students evaluated the laboratory, see Table III. The evaluation was given by grades (1.0 – very good; 5.0 – inadequate). In the free form evaluation, the students suggested a higher and up to date integration between the online- and on-site-parts of the laboratory and the different software solutions used. A more detailed evaluation of the course and especially the laboratory is currently in the design phase and will be executed on the next run of the course in winter 2023.

TABLE III
LABORATORY EVALUATION, $n = 5$

Question (EN translation)	Question (DE original)	Result
How do you evaluate the structure of the course?	Wie bewerten Sie den Aufbau der Lehrveranstaltung?	$\mu = 1.25; \sigma = 0.5$
In your opinion, how much did the lecturer encourage active participation?	Wie beurteilen Sie die Einbindung der Studierenden in die Lehrveranstaltung?	$\mu = 1.4; \sigma = 0.55$
In your opinion, was the content of the course illustrated well by exercises and examples?	Finden Sie, dass die Lehrinhalte durch Beispiele und Übingen gut veranschaulicht wurden?	$\mu = 1.4; \sigma = 0.55$
How do you rate the material provided for the course?	Wie beurteilen Sie die angebotenen Unterlagen?	$\mu = 1.4; \sigma = 0.55$
What is your over all assessment of the course?	Wie ist Ihr Gesamteindruck von der Lehrveranstaltung?	$\mu = 1.2; \sigma = 0.45$

V. CONCLUSION

The use of digital media to improve the didactic design depends on the learning outcomes and the type of studies. In the use case presented here, a collaborative robotics laboratory is designed for the use in a blended learning type setting of a university of applied science's graduate course in industrial engineering studies [18]. The learning outcomes were derived from [10], [11] and [12]. The methods used to design the didactics of the laboratory follow [13], [14], [15], [16], and [17]. As an example, the didactic design was used in an undergraduate course in industrial engineering studies. The results of this course were very promising, both from the lecturer's and the students' point of view.

From the experience gained, a specification for the laboratory's equipment and the required hard- and software for the remote use of the laboratory are derived.

In the next step, the laboratory used will be prepared for remote learning and teaching using the CrossLab's remote laboratory infrastructure. Additionally, a thorough evaluation of the remote lab vis-à-vis in-present-experimentation is currently underway.

REFERENCES

[1] H. Kagermann, W. Wahlster, and J. Helbig, *Recommendations for implementing the strategic initiative INDUSTRIE 4.0 securing the future of German manufacturing industry ; final report of the Industrie 4.0 working group*. acatech – National Academy of Science and Engineering, Germany, 2013.

[2] VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik, "Cyber-Physical Systems: Chancen und Nutzen aus Sicht der Automation," Tech. Rep., 2013.

[3] D. F. Abawi, V. Ahrens, R. Bäßler, M. Brettel, U. Dittmann, H. Englberger, W.-C. Hildebrand, Y. Leipnitz-Ponto, A. Merchiers, G. Olsowski, D. Pumpe, A. Schätter, B. Schmager, C. Schuchardt, C. von Hirschhausen, M. Werner, and H. Zadek, *Qualifikationsrahmen Wirtschaftsingenieurwesen*, 3rd ed., Fakultäten- und Fachbereichstag Wirtschaftsingenieurwesen e. V., Verband Deutscher Wirtschaftsingenieure (VWI) e. V. (Hrsg.), Ed., 2019.

[4] A. E. Tekkaya, C. Terkowski, M. Radtke, U. Wilkesmann, C. Pleul, and F. Maevus, *Das Labor in der ingenieurwissenschaftlichen Ausbildung: Zukunftsorientierte Ansätze aus dem Projekt IngLab*. acatech – National Academy of Science and Engineering, Germany, 2016.

[5] I. Aubel, S. Zug, A. Dietrich, J. Nau, K. Henke, P. Helbing, D. Streitferdt, C. Terkowsky, K. Boettcher, T. R. Ortelt, M. Schade, N. Kockmann, T. Haertel, U. Wilkesmann, M. Finck, J. Haase, F. Herrmann, L. Kobras, B. Meussen, M. Soll, and D. Versick, "Adaptable digital labs - motivation and vision of the crosslab project," in *2022 IEEE German Education Conference (GeCon)*, 2022, pp. 1–6.

[6] V. Ahrens, *Abschlussarbeiten richtig gliedern in Naturwissenschaften, Technik und Wirtschaft*, 2nd ed. Vdf Hochschulverlag AG an der ETH Zürich, 2020.

[7] International Organization for Standardization, "Robots and robotic devices – Safety requirements for industrial robots — Part 1: Robots," Standard, 2011, ISO 10218-1:2011-07.

[8] ——, "Robots and robotic devices – Safety requirements for industrial robots — Part 2: Robot systems and integration," Standard, 2011, ISO 10218-2:2011-07.

[9] Brandt, Nico and Brinker, Helmut and Meussen, Bernhard and Mora, Javier und Schönfeld, Tim, "Kollaborierende Robotik in der Montage von Baugruppen," in *NORDBLICK Forschung an der NORDAKADEMIE*, vol. 4, 2017.

[10] L. D. Feisel and A. J. Rosa, "The Role of the Laboratory in Undergraduate Engineering Education," *Journal of Engineering Education*, vol. 94, no. 1, p. 121–130, 2005. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/j.2168-9830.2005.tb00833.x

[11] M. Soll and K. Boettcher, "Expected learning outcomes by industry for laboratories at universities," in *2022 IEEE German Education Conference (GeCon)*. Berlin, Germany: IEEE, 2022.

[12] K. Boettcher, C. Terkowsky, T. Ortelt, I. Aubel, S. Zug, M. Soll, J. Haase, B. Meussen, D. Versick, M. Finck, P. Helbing, J. Nau, and D. Streitferdt, "Work in progress – did you check it? checklist for redesigning a laboratory experiment in engineering education addressing competencies of learning and working 4.0," in *20th International Conference on Remote Engineering and Virtual Instrumentation (REV2023)*. Thessaloniki, Greece: Springer Nature, 2023, in press.

[13] B. Bloom, *Taxonomy of Educational Objectives: The Classification of Educational Goals*, ser. Taxonomy of Educational Objectives: The Classification of Educational Goals. David McKay Company, 1956.

[14] D. R. Krathwohl, "A revision of bloom's taxonomy: An overview," *Theory Into Practice*, vol. 41, no. 4, pp. 212–218, 2002. [Online]. Available: https://doi.org/10.1207/s15430421tip4104_2

[15] D. Kennedy, *Writing and using learning outcomes: a practical guide*. Cork, Ireland: University College Cork, 2006.

[16] G. Reinmann, "Studientext Didaktisches Design," Fünfte korrigerte und ergänzte Version, https://gabi-reinmann.de/wp-content/uploads/2013/05/Studientext_DD_Sept2015.pdf, last accessed 2023-04-03, Tech. Rep., 2015.

[17] J. Biggs, "Enhancing teaching through constructive alignment," in *Higher Education*, vol. 32, 1996, pp. 347–364. [Online]. Available: https://doi.org/10.1007/BF00138871

[18] Hieronymus, Martin and Finck, Matthias and Meussen, Bernhard, "Cyber-physische Labore: Abschlussbericht des von der NORDAKADEMIE-Stiftung geförderten Projekts "CPL - inverted laboratories"," Nordakademie - Hochschule der Wirtschaft, Arbeitspapiere der Nordakademie 2022-01, 2022. [Online]. Available: https://EconPapers.repec.org/RePEc:zbw:nordwp:202201

[19] Council of the European Union, "Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast) (Text with EEA relevance)," 2006. [Online]. Available: http://data.europa.eu/eli/dir/2006/42/oj

[20] J. Nau and M. Soll, "An extendable microservice architecture for remotely coupled online laboratories," in *Proceedings of the 20th International Conference on Remote Engineering and Virtual Instrumentation (REV2023)*, 2023, p. 186–197, in press.