Work in Progress – Did you check it? Checklist for Redesigning a Laboratory Experiment in Engineering Education addressing Competencies of Learning and Working 4.0

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Abstract. Due to the possibilities of digitalization, the world of work is undergoing a profound change towards Industry 4.0 and related Learning and Working 4.0. In this context, new competences are expected from employees, which must also be addressed in STEM disciplines, especially in higher engineering education. Lab courses are particularly suitable for this, because here students can actively work on devices and potentially cyber-physical systems. This contribution is the undertaking of a group of lab teachers from various disciplines working on the joint project CrossLab to formulate what they consider the important aspects of lab teaching as learning outcomes for Industry 4.0. Furthermore, as a final goal, they will be transferred into a checklist that can be used in the implementation of existing and newly designed lab experiments with regard to the required competences of Learning and Working 4.0. Constructive Alignment forms the pedagogical framework, in which intended learning outcomes, teaching-learning activities and learning outcome monitoring must be thought through and planned as a whole. The checklist will extend an existing checklist for the thirteen conventional fundamental lab learning-objectives according to Feisel and Rosa. This work in progress describes first results of this attempt.

Keywords: Laboratory Pedagogy, Higher Engineering Education, Industry 4.0

1 Basics

With increasing technical development, the professional world has become more challenging, which has increased the demand for a well-educated human work force over the last hundred years. This led to an increase in the proportion of students in the population, which means that it is not only the best-performing and most motivated parts of the population that pursue university studies. Since more engineers are needed for further interconnected digitalization in Industry 4.0 and for a development towards a green, climate-neutral industry, it is the task of the teaching staff to educate all students as best as possible [1,2].

One basis for planning courses is Biggs' Constructive Alignment (CA) [3]. In the first step, the course is divided into intended learning outcomes (ILO), teaching-learning activities (TLA) and ILO monitoring (ILOM). The teaching staff has the task of aligning the TLA in such a way that exactly the identified and focussed ILOs are addressed. This often requires a deeper reflection on their own course. In the ILOM, it must then be checked whether exactly these ILOs have been achieved. The ILOs should be made transparently clear to the students before the course.

1.1 Laboratory Education

In engineering education, teaching and learning in the lab is an important component. Labs can be divided into different types [4] (see Table 1). Most common are probably integrated labs and lab experiments in basic lab courses.

Table 1. Different laboratories used in education. Excerpt from [4].

Laboratories	Example
Research lab	Own research based on experiments
Game-based lab	Escape room
Maker space	Lab with 3D printers for developing and printing
Basic lab course	Learning principles of work in laboratories
Mini lab	Focused on time and content, e.g., visualization types or derivations in fluid mechanics [5, 6]
Integrated lab	Demonstration experiment in lecture

In instructional labs, an increase in competence can be expected with increasing independence and autonomy [4]. These tasks partly reflect the lab types and are listed in Table 2. The lowest increase in competence is to be expected in demonstration experiments as in experimental lectures and the highest competence increase in lab experiments designed to address self-developed open research questions. Although a change in the assignments causes only a slight change in the experiments, many labs only repeat what already has been learned in the courses.

Table 2. Different assignments used in laboratory education. Excerpt from [4].

Inquiries	Example
Scientific inquiry	Conducting own experiments to answer open research questions
Open inquiry	Open assignment without a guideline [7]
Guided inquiry	Clear assignment with a guideline [8]
Structured inquiry	Clear assignment embedded in a code-like guideline
Confirmation inquiry	Students experiment to confirm what they learned in a course
Demonstration inquiry	Demonstrated experiments in a lecture, exercise, tutorial etc. [8]

Increasing competence can also take place through the setting in which the lab experiments take place. A classification according to [9] is shown in Table 3 and partly overlaps with the types of labs (Table 2) and the tasks (Table 2).

Table 3. Different assignments used in laboratory education. Excerpt from [9]

Inquiries	Description
Research-based learning	Conducting own experiments to answer open research questions
Scenario-based learning	Project work embedded in a real-world scenario; students act like an employee
Project-based learning	Problem-based learning enriched by elements of project work
Problem-based learning	Experiment is based on solving a problem
Task-based learning	Experimenting with a cookbook like scriptum

Feisel and Rosa [10] defined 13 fundamental learning objectives (FLO) of undergraduate instructional labs that engineering students should acquire throughout their studies (see Table 4). These have been converted into a checklist in a book publication by [9]. This is based on the framework of CA to formulate and address ILOs, the levels of TLA and an aligned competence-oriented examination, enriched by thoughts on the professional purpose of the ILO.

Table 4. Fundamental learning objectives for undergraduates in laboratory education from [10].

Learning objective	Description
1. Instrumentation.	Applying instrumentation or software tools for measurement.
2. Models	Identifying strengths and limits of models. Validating a relationship between measured data and physical principles.
3. Experiment	Specifying and implementing equipment and procedures. Interpreting resulting data for characterization.
4. Data Analysis	Collecting, analysing, and interpreting data to form conclusions.
5. Design	Designing, building, or assembling parts or systems, using appropriate methodologies. Testing and debugging to satisfy requirements.
6. Learn from Failure	Identifying unsuccessful outcomes, identifying effective solutions.
7. Creativity	Demonstrating independent thought and capability in solving real-world problems.
8. Psychomotor	Selecting, modifying, and operating engineering tools.
9. Safety	Identifying health, safety, and environmental issues and deal with them responsibly.
10. Communication	Communicating about laboratory work with a specific audience.
11. Teamwork	Working in teams: structure individual and joint accountability.
12. Ethics in Laboratory	Behaving with highest ethical standards, interacting with integrity.
13. Sensory Awareness	Using human senses to gather information.

1.2 Joint-Project CrossLab

The aim is to develop student-centred, flexibly combinable cross-reality labs (remote, ultra-concurrent, mixed reality and simulations) to address competences of the Work 4.0 in higher education [11]. The labs are based on the instructional principles listed above. Their optimal use is to be ensured by an ILO recommender, which suggests the optimal lab experiment for specific ILOs. The participants are from the NORDAKADEMIE University of Applied Sciences, TU Bergakademie Freiberg, TU Ilmenau and TU Dortmund University. The disciplines represented are mechanical engineering, biochemical and chemical engineering, computer science, chemistry, and higher education pedagogy.

1.3 Industry 4.0

Working in Industry 4.0 does not mean, that subject specific ILOs are obsolete [12] but overlaid by new requirements arising from Learning and Working 4.0. Therefore, the FLOs of [10] or the regular ways to teach [13] are still to be addressed but maybe need to be updated or supplemented. In Industry 4.0 the work with the organization principles technical assistance, information transparency, work with cyber-physical systems or digital twins and connected systems [14] seems to become fundamental. Self-organization, self-direction, creativity [15], ethical decision-making [16] the collaboration in teams, are expected to get more important. Further, in research and development, engineers will not get a detailed cookbook-like script, but they have to meet the expectations of independent work without much help from superior levels [17]. A survey on the expectations of lab teaching in different levels of industrial companies shows that their expectations extend the FLOs of [10] by i.) *Know Industry Environment*, ii.) *Overview Over Larger Context*, and iii.) *Working Mindset* [18].

2 Method

All researchers of the CrossLab project had theoretical or practical teaching experience and conducted a workshop of several half-days. This was organised by academic staff from a higher education institution who are also part of the project.

In a first meeting, the technical possibilities of digitalization and cross-reality labs were presented, and instructional basics for teaching and learning especially in the lab were provided. In the second part, the participants had to define ILOs of Industry 4.0, which they would like to address in their labs. Three groups were created, and various studies were provided as material for this. The results were then presented in a third part, discussed and, following [10], summarised in FLOs, which do not claim to be complete. Subsequently, in group work and discussion, an attempt was made to translate the results into the first parts of a checklist. The original checklist [9] provides for each ILO a definition of the competences students should have after attending the lab experiment. According to [9], the questions the teachers have to answer for the CA are listed below. Q1 addresses the ILO, Q2 and Q3 the TLA. Q4 addresses the purpose and therefore gives a hint to foster motivation and Q5 and Q6 address the ILOM and would be specific to the lab experiment.

1. What do the students have to learn exactly after attending the experiment? (Q1)
2. Through which concrete actions should students learn regarding the ILO? (Q2)
3. To what extent/level should students do this? (Q3)
4. What is the relation to later professional life regarding the specific ILO or what is it needed or used for in later professional life? (Q4)
5. How will you know that the students through the teaching/learning activity have achieved the ILO? (Q5)
6. How can this be competence-oriented examined and integrated in the ILOM? (Q6)

3 Results

Seven ILOs in lab education were identified, which do not exactly fit into the FLOs of [10] and are outlined below.

3.1 ILO 14: to develop personality

Students can identify personal and team-related problems and to initiate action to resolve it regarding one’s own limits, conflict management, interface competence etc.

On the lowest level teachers send students to a statistic advice centre, on a mediocre level, students recognize their lack of competence, and the teacher sends the students to the centre and on the highest level, students could recognize their lack of competence and search on their own where they can find solutions. This is distinct from the FLO “teamwork” as the ILO is not to act in a team but reflecting personal skills, decisions and identifying possible solutions to develop the personality in every context.

3.2 ILO 15: to improve one’s style of learning and working mindset

Students can reflect and improve their individual style of learning and working regarding work-life balance, target-oriented instead of time-oriented work, resilience, and autonomy. This could be addressed by open inquiries or impossible assignments, where students must identify and proof it or changing goals.

3.3 ILO 16: to develop critical thinking and acting sustainably

Students can assess the consequences of their own actions and their own experiments or developments, and to pursue better alternatives regarding ethics, environment, costs, and social consequences (regarding the sustainable development goals by the UNESCO [19]). This could be addressed by ethically questionable tasks or boundary conditions. On a low level, the students could reflect it after the experiment, on a mediocre level they must reflect during the experiment regarding the assignment and on a high level the students should reflect during the experiment and change their behaviour independently.

3.4 ILO 17: to think out of the box (overview over larger context, scientific inquiry)

Students can identify gaps or limitations in knowledge/technology independently and develop new experiments or measuring devices for these independently or pursue other research questions with existing methods/equipment. This ILO is like research-based learning or a scientific inquiry and thereby exceeds the FLO “creativity”. The teacher could foster it by providing not-practicable measurement devices. On a low level, students recognize it, on a mediocre level students develop devices to measure quantities and on a high level, students recognize the needs, develop solutions, and implement them independently.

3.5 ILO 18: to develop self-directed learning skills

Students can constantly reflect and recognise their learning needs and the time required for this. They can find suitable, trustworthy digital learning resources and to use them for learning processes, adapting their learning behaviour to digital learning resources and the chosen learning strategies to integrate current knowledge into their own work and to support team members in learning or implementing this process.

Teachers can address it by an incomplete scriptum or assignment. On a low level, material is given on a mediocre level a library of material is given and on a high level, students should be able to identify useful material by their own and should also be able to deal with faked webpages/information.

3.6 ILO 19: to work with cyber-physical systems (CPS)

Students can work with CPS recognize and exploit the specific characteristics of CPS like decentralized networking and autonomous decisions, assistance systems, information transparency [14], e.g., by using VR or AR techniques [8, 20, 21] new production methods, and process control/management. Different levels are using of the specific characteristics under supervision, the autonomous usage, and the development of tools regarding CPS characteristics.

3.7 Learning outcome 20: to organize and manage data with new methods

Students can document, organize, and preserve created research data, processes, experiences in such a way that others can continue to work with them and to link various existing data with new methods (e.g., artificial intelligence) to analyse them. Teachers could interlink several groups producing data, while on a low level, teachers demonstrate the methods, on a mediocre level, students implement the methods using a cookbook-like scriptum and on a high level, students autonomously recognize the need to use such methods. The checklist has already been used in a multi-perspective framework to evaluate existing lab materials using content analysis [22].

4 Conclusion and Outlook

The use of the checklist on the existing lab experiments generated a clear reflection among the teaching staff about the ILOs that were addressed and desired. The focus on the Working World 4.0 resulted in new ILOs. The identified ILOs partly overlap with those of [10] but expand them gradually: the FLO are somewhat limited to competences and skills in a professional context, while the new ILOs are also set in a private and societal context. The 7 ILOs should be condensed and 14, 15 and 18 may form a single outcome as well as 20 may be integrated into 19. Outcome 17 may also be more a possibility to increase the motivation of students, but the involved teachers think that helping mankind to survive or to improve should be an ILO. An attempt will be made to address further ILOs for existing lab experiments with the help of the checklist and to offer them in various alternative designs with the same hardware setup. This enables to address different ILOs with one lab experiment and students, or teachers can identify the experiments and alternatives that suit them. As a result, a list of ILOs is planned to encourage the implementation of CA about subject specific ILOs and Learning and Working 4.0 objectives and to offer levels of design for all ILOs, so that developers of lab experiments can set the focus directly in the planning.

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