Expected Learning Outcomes by Industry for Laboratories at Universities

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***Abstract*—This paper presents an exploratory study which has the goal of finding learning outcomes desired by the industry for laboratories at universities. To do this, a total of nine industry representatives were interviewed. All of the interviews were recorded, transcribed and inductively coded. The found categories were then combined into larger learning outcomes. Besides confirming some already established learning outcomes, this study found three new learning outcomes: Know Industry Environment, Overview Over Larger Context, and Working Mindset / Soft Skills. In addition, a wish for a laboratory environment where students can experiment more freely was expressed. Since this was a purely qualitative study, the next step should include the validation of how far these learning outcomes are actually desired by students, academia and the industry.**

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

I. Introduction

The business world is changing significantly in the direction of Industry 4.0 [1]. Increasing digitisation will not only make the world of work more technical, but is also expected to require new skills from workers [2]. At the same time, the old skills are not to be completely replaced by new ones, but rather added to. This circumstance must be taken into account in STEM education at universities.

Laboratories play an important role in STEM education at universities [3]. They do not only allow the acquisition of important skills [4], but also allow students to get a better understanding of the domain knowledge they need to learn [5]. Because of this, well-designed laboratories are desired for university education.

The use of remote labs addresses the handling of new technology and is in principle suitable for the implementation of competencies for Industry 4.0 [6]. The usage of immersive laboratories in virtual reality [7] enables the addressing of organisational design principles of the work environment of Industry 4.0 stated by [8]. In addition, working methods of the Industry 4.0 can be implemented in remote laboratory experiments [9], while implementing the same in traditional laboratories is more difficult.

Since collaborations between universities and industry can be beneficial for both sides [10] and such collaborations should include both research and education [11], it would be useful if students acquire the skills needed by the industry through their study course. Based on this, the paper presents an exploratory study to answer the research question: What learning outcomes of laboratories are expected by the industry?

II. Learning Outcomes for Laboratories

One part of the Bologna Process, which tried to reform and unify university education across Europe, was to improve higher education including that every course / module should be defined by their learning outcomes [12], [13]. A learning outcome in this sense describes what students should know / understand / demonstrate after a course, and that knowledge / understanding / demonstration must be observable by the teacher [12].

Because of this, laboratory education in universities should be specified in terms of learning outcomes. Based on a colloquy with experts from engineering education [14], one important work in terms of defining learning outcomes for laboratories was conducted by Feisel and Rosa [15]: They defined a total of 13 learning outcomes undergraduate students should achieve by completing all required laboratory courses, which can be found in Tab. I.

In theory, laboratories at universities are making the transition from traditional to outcome-focussed teaching [16]. In reality, the realisation of laboratory experiments is still partly oriented on cook book scripts. In these, students are given little or no opportunity for self-directed or explorative learning, but rather the procedure is more or less rigidly prescribed. According to Felder and Brent [17], the usual laboratory teaching is not sufficient to prepare students for later working life. For example, in research and development, there are usually no scripts with clearly defined tasks and methods to be applied. Rather, the problem itself is incompletely defined and the approaches unclear, with work being done as independently as possible without much support from superiors. This can

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TABLE I
LEARNING GOALS FOR LABORATORIES AS FOUND BY FEISEL AND ROSA [15].

Num.	Name	Description
1	Instrumentation	Use the appropriate tools, instruments and software to conduct the experiment.
2	Models	Know which strengths and limitations current theoretical models have and how they can be used to predict real-world behaviours.
3	Experiment	Find the correct approach, equipment, and procedures to conduct an experiment. Be able to implement the procedures and interpret the outcome of the experiment.
4	Data Analysis	Be able to handle the data associated with an experiment. This includes the collection, analysing and interpretation of data.
5	Design	Have the ability to design, build and assemble a system/product or a part thereof. Know which methodologies, equipment and materials must be used. Handle requirements from clients, write system specifications and validate such specifications.
6	Learn from Failure	Identify when an experiment fails, find the problem in the experiment (e.g. faulty parts, problematic experiment design) and use this knowledge to build a better / improved experiment.
7	Creativity	Show creativity in experiments and in solving real-world problems.
8	Psychomotor	Use your senses and abilities while operating laboratory equipment.
9	Safety	Relate technological processes or laboratory activities to potential health, safety and environmental issues and deal with them in a responsible manner.
10	Communication	Communicate effectively and comprehensively, about laboratory work (from summaries to comprehensive technical reports) both orally and in writing, to targeted audiences.
11	Teamwork	Collaborate effectively, including: organizing individual and shared responsibilities (assigning roles, responsibilities, and tasks as well as monitoring progress; meeting deadlines; and integrating individual contributions into a final output).
12	Ethics in the Laboratory	Act in compliance with the highest standard of ethics, including objective disclosure of information and acting with integrity.
13	Sensory Awareness	Using sensory perception to acquire information and to make well-founded decisions when formulating conclusions about real problems.

be considered as another learning outcome, which will be achieved in laboratory experiments.

CrossLab[1] is a joint project of four German universities with partners from different STEM-faculties and laboratory education. It is funded by the *Stiftung Innovation in der Hochschule*[2] and aims to prepare students for the requirements of the working world 4.0 through laboratory teaching. It is envisioned that new laboratory experiments will be developed jointly by different disciplines and colleges, and students from different colleges and disciplines will be required to work together on laboratory experiments. These laboratory experiments are mainly remote laboratories, simulations or mixed reality laboratories. The project aims to offer these freely combine laboratories to teachers and learners. The pedagogic planning of the laboratory experiments is based on Constructive Alignment [18] and the selection of the laboratory experiments is to be supported by a recommender system for learning outcomes. For this reason, different industry representatives were asked which learning outcomes should be addressed in the teaching of laboratories according to their experience.

[1]https://cross-lab.org/

[2]https://stiftung-hochschullehre.de/

III. STUDY DESIGN

The study was designed as expert interviews [19]–[22] taking around 10-30 minutes per interviewed person, see Fig. 1 for the translated interview questions. All interview partners were invited based on cooperation with the universities as well as personal contacts. All interviews were conducted in the German language. After a short introduction, all participants were asked which learning outcomes (both in terms of soft skills as well as in terms of domain knowledge) they think students should learn at university laboratories. After that, they should explain whether and why laboratories as a whole are important for university education. At the end, participant could give comments on any topic they feel was left open. The interviews were recorded for later analysis.

For this study, a total of nine industry representatives were interviewed between February 2022 and June 2022. All interviewees gave their informed consent for the interview. The industry representatives had different backgrounds (cheminformatics, electrical engineering, insurance, medicine technology, public transportation, 3 x software development, vehicle manufacturing), positions (ranging from new graduates to management) and company sizes (ranging from small companies with a couple of employees to large, globally operating companies). The wide selection of background should ensure that the collected learning outcomes are representative for the industry as a whole in addition to ensure that no important view is missing from the study.

After the interviews were finished, all recordings were transcribed to text. The texts were first coded and those codes were inductively categorised (i.e. with no prior categories) [22]. Based on the categories, different learning outcomes were derivated. Each learning outcome found consists of multiple categories and each category could appear in multiple learning outcomes.

IV. RESULTS

In the transcribed interviews, a total of 81 text passages were coded. These coded text passages were sorted into 31 categories. You can see the detailed numbers of codes per category in Tab. II as well as their frequency.

Based on the categories, a total of eleven learning outcomes were defined. While most of the learning outcomes are similar to the ones of Feisel and Rosa [15], a few new ones were discovered. An overview over the newly identified learning

I: Thank you a lot for joining me today on this interview. My hope is that with your help, we are able to improve the teaching at universities, especially for laboratories, in our current project CrossLab.
Q: Can you describe your company in a few sentences?
I: Now I want to focus on laboratories at university. A laboratory in this context is a course focussed on practical work and practical knowledge, in contrast to - for example - lectures. Some examples would include a robot laboratory, where students can work with as well as on robots, an IT security laboratory, where the security of computer systems can be tested, or a chemical laboratory, where various chemical experiments can be conducted.
Q: Are there any skills students should learn in such laboratories? I'm interested in both special knowledge domains as well as soft skills.
CQ: [If the interviewee mostly mentioned soft skills] Is there any knowledge domain students should learn through laboratories?
CQ: [If the interviewee mostly mentioned knowledge domains] Are there any soft skills students should learn in laboratories?
CQ: If we now look at laboratories at universities as a whole: How important are such laboratory courses for university education? Are there any benefits in education?
CQ: [If the interviewee mentioned laboratories are beneficial, but does not mentioned why in detail] Why are laboratories beneficial for university education? [be sure there is more to the answer than 'because it is practical work']
Q: We are about to finish the interview. Do you still want to mention something about one of the prior topics? Do you have anything else you want to tell me?
E: Thank you for the interview. We hope that with your help, we can improve university education.

Fig. 1. Translated interview questions for the expert interview. The questions were originally in German and translated for this paper. **I** stands for *introduction*, **E** stands for *end text*, **Q** for *question* and **CQ** for *conditional question*. Comments for interviewers are in brackets.

outcomes as well as the associated categories can be found in Tab. III. The learning outcomes are as follows:

- **Data Literacy**: Students should learn how to collect data, interpret data and draw conclusions out of the collected data. The data and conclusion should be made public, when possible and reasonable.
- **Explorative Learning**: Students should have the ability and the motivation to just try things out. It is important here that laboratories provide enough freedom and time for the students to just experiment and figure things out by themselves, especially the access to instruments should not only have restrictions where strictly necessary.
- **Handling Failures**: Errors, mistakes and failures are a normal part of laboratory activities, both in education as well as in industry work. This makes it important for the students to find a mature way of handling those problems. This includes being able to admit and communicate mistakes they have done, handling any criticism they might receive and giving constructive feedback where necessary.
- **Know Difference Between Theory and Practice**: While theoretical models are helpful, they can only capture a limited view of the reality. Because of this, problems arise when trying to translate these models into reality. Students should therefore have knowledge of these problems and should be able to work around them.
- **Know Industry Environment**: From the perspective of industry representatives, it would be desirable that students know the typical work found in industry. For this, laboratories provide the possibility to experience real-world scenarios in a controlled environment. This could go as far as students using laboratory courses as a way of vocational counseling. For this to work, the instruments accessible to the students should be up-to-date.
- **Knowledge-Based Outcomes**: This overarching, meta-level learning outcome encapsulates all categories connected to domains of knowledge. It is important to note that most interviewed industry representatives mentioned that the exact domain of knowledge is specific to the

TABLE II
CATEGORIES INDUCTIVELY FOUND IN THE TRANSCRIBED INTERVIEWS. EACH CATEGORY CONSISTS OF MULTIPLE TEXT PASSAGES IN THE INTERVIEW, THE NUMBER OF TEXT PASSAGES (NUM. PASS.) CAN BE FOUND IN THE TABLE.

Category	Num. Pass.
ability to work independently	4
abstract thinking	1
communication skills	2
data literacy	1
demonstration of theoretical models	3
giving feedback	1
handling criticism	1
handling failures	2
hands on mentality	1
have an overview over the domain knowledge	1
have enough freedom to experiment	1
instruments must be up-to-date	2
keep overview over whole production line	1
knowing problems of translating knowledge to practise	6
knowledge depends on later work environment	7
knowledge is not important to learn in laboratories	1
knowledge: IT security	2
knowledge: software development	2
problem solving skills	4
project management	1
realistic laboratory setups	1
sense of responsibility	1
teamwork	7
training in a stable environment	1
trying things out	2
usage of instruments	6
use laboratory as vocational counseling	2
willingness to learn	2
working remote	2
writing documentation	2

later occupation of the student, with one person mentioning that the soft skills would be way more important since the pure knowledge could be learned somewhere else (e.g. lectures). It was suggested that because of this, having a broad overview over the whole domain of knowledge might be important. The two knowledge domains mentioned explicitly are *IT security* and *software development*.
- **Overview Over Larger Context**: In the industry, you rarely work completely isolated on a problem. Instead, you work with different persons of different areas of expertise on the same project / production line. To work productively, it is therefore important for a student to know the context in which they are working, i.e. have an overview over the complete production line / project and have a broad knowledge of the complete (and maybe even adjacent) domains.
- **Using Instruments**: Students should be able to handle the tools found at a normal working place. Especially for the modern industry, this includes being able to work efficiently from a remote location. As mentioned before, it would be useful to keep the tools of the laboratories up-to-date for achieving this outcome.
- **Teamwork**: When you are working in the industry, you are typically working in a team with other persons. This is why it is important for students to learn efficient teamwork, including communication skills.
- **Working Mindset / Soft Skills**: This learning outcome consists of many soft skills required at modern workplaces. These include the ability to work independently of other persons, abstract thinking, communication skills, problem solving skills, the willingness to learn (i.e. lifelong learning) and many other skills.
- **Writing / Documentation Skills**: One part of industry work consists of writing protocols, writing documentations, written communication and similar tasks. Laboratories should give an opportunity to train and improve written expression and grammar.

V. Discussion

We can compare the learning outcomes found in this study to the ones found by Feisel and Rosa [15]. The comparison can be found in Tab. III. Besides confirming some of the learning outcomes (namely *Experiment*, *Learn from Failure*, *Models*, *Instrumentation*, *Psychomotor*, *Teamwork*, and *Communication*), this study was able to identify three new learning outcomes desired by the industry (namely *Know Industry Environment*, *Overview Over Larger Context*, and *Working Mindset / Soft Skills*).

One of those learning outcomes, *Know Industry Environment*, is quite specific to the work students might later do in industry. At a first glance, this might not seem interesting for academia or students wanting to go into academia. However, if we keep in mind that industry cooperations are in fact beneficial for both sides [10], it might be desirable for academia to keep this learning outcome in mind. In academia, something similar would be networked knowledge, where students have the capability to connect knowledge from one specific area to another and to transfer abilities and methods from one field to another (e.g. balancing in fluid mechanics, technical mechanics, transport processes, and chemical reactions). Here it would be a possibility that faculty members of different specific areas create one laboratory experiment together.

The other two learning outcomes have a different problem. Both *Overview Over Larger Context* and *Working Mindset / Soft Skills* are outcomes that are not easily observable by a teacher. While you can at least test for the knowledge of the *Overview Over Larger Context* learning outcome (which does not cover the whole learning outcome), this is not possible for all parts of the *Working Mindset / Soft Skills* learning outcome (e.g. how do you test the *willingness to learn* of a student?).

We should also look at the learning outcome *Exploratory Learning*. While this can be compared to Feisel and Rosas [15] learning outcome *Experiment*, this could also be seen as a general setting in which experiments should take place, i.e. students should not have a strict procedure they must follow, but they should have enough freedom and time to develop their own approaches.

A special mention should go to the *Knowledge-Based Outcomes*. These are not traditional learning outcomes, but represent the knowledge that should be taught in a laboratory courses. Since most interviewed industry representatives say that the required domain knowledge depends on the later work area, it is hard to make any recommendations here. However, it seems that through self teaching and the current curricula, there are currently no problems in this area.

Interestingly, the following learning outcomes of Feisel and Rosa [15] were not found: *Creativity*, *Safety*, *Ethics in the Laboratory* and *Sensory Awareness*. Some of these can be found in categories but have not translated into an own learning outcome: You can argue that *Safety* and *Ethics in the Laboratory* are part of the category *sense of responsibility* and *Creativity* is part of *trying things out*. However, especially the more physical learning outcome *Sensory Awareness* was not focussed by the interviewed industry representatives.

As for the methodology in this study, since this was an exploratory study and designed as such, it is not possible to extract how widely the learning outcomes discovered in this study are actually important. In addition, since a wide variety of industry representatives were interviewed, we hope that we have found all important learning outcomes. Since we only had nine interviews, there might be the possibility that some learning outcomes desired by the industry might be overlooked by the study.

In this study, all interviews were coded inductively [22]. An other approach would be to use existing learning outcomes such as Feisel and Rosa [15] and only when a text does not fit into any existing category, a new code is created. The authors tried to use such an approach, which revealed that the learning outcomes suggested in the interviews do not fit well into the categories of Rosa and Feisel [15], often combining multiple learning outcomes (e.g. combining

TABLE III

LEARNING OUTCOMES EXTRACTED FROM EXPERT INTERVIEWS INCLUDING ASSOCIATED CATEGORIES. THE SAME CATEGORY CAN APPEAR IN MULTIPLE OUTCOMES. IN ADDITION, IT IS POINTED OUT WHERE LEARNING OUTCOMES ARE SIMILAR TO FEISEL AND ROSA [15].

Found Learning Outcome	Associated Categories	Comparable Outcome of Feisel and Rosa [15]
Data Literacy	data literacy	Data Analysis
Explorative Learning	have enough freedom to experiment trying things out	Experiment
Handling Failures	communication skills giving feedback handling criticism handling failures	Learn from Failure
Know Difference Between Theory and Practice	demonstration of theoretical models knowing problems of translating knowledge to practise	Models / Design
Know Industry Environment	have an overview over the domain knowledge instruments must be up-to-date knowing problems of translating knowledge to practise realistic laboratory setups training in a stable environment use laboratory as vocational counseling	
Knowledge-Based Outcomes	have an overview over the domain knowledge knowledge depends on later work environment knowledge is not important to learn in laboratories knowledge: IT security knowledge: software development	
Overview Over Larger Context	have an overview over the domain knowledge keep overview over whole production line project management	
Using Instruments	instruments must be up-to-date sense of responsibility usage of instruments working remote	Instrumentation Psychomotor
Teamwork	communication skills giving feedback handling criticism teamwork	Teamwork
Working Mindset / Soft Skills	ability to work independently abstract thinking communication skills giving feedback handling criticism hands on mentality problem solving skills sense of responsibility trying things out teamwork willingness to learn	
Writing / Documentation Skills	giving feedback writing documentation	Communication

Instrumentation and *Psychomotor*) or differentiating more (e.g. adding aspects of giving / receiving feedback to *Learn from Failure*). Therefore, this approach was not followed through by the authors.

VI. CONCLUSION AND FUTURE WORK

In the exploratory study, a total of eleven learning outcomes for laboratories desired by industry were found. Three of those learning outcomes (namely *Know Industry Environment*, *Overview Over Larger Context*, and *Working Mindset / Soft Skills*) were not previous described by Feisel and Rosa [15]. A fourth learning outcome, *Explorative Learning*, could be interpreted as a wish to change the current environment of laboratory courses so students can experiment more freely and are not bound to tight laboratory procedures.

Since the study was designed as an exploratory study, it can not capture how far the learning outcomes are actually desired by students, academia and the industry. This way, the found learning outcomes could be validated. For this, we plan to do a quantitative study where a larger pool of participants should rate different learning outcomes (including the ones found in this study) for how useful they perceive them to be in laboratory courses.

Once validated, it would be useful to see how far these new learning outcomes are already implemented in existing university laboratory courses. Where applicable, it could be researched how to implement these learning outcomes into existing laboratory courses.

The authors are currently working in the Project CrossLab, which has the goal of improving laboratory education at universities. The desired learning outcomes found in this study are mostly envisioned in the CrossLab project and some may be better addressable than in a real laboratory. One important result of this study is the indication that industry representatives want laboratory experiments in which networked knowledge is taught (i.e. *Overview Over Large Context*). This can, for example, be achieved by combining existing labs or having labs be created by staff from different disciplines. By combining students from different subject areas or institutions, the learning outcome *Teamwork* would be addressed, too. The learning outcome *Know Industry Environment* is planned to be covered by realistic real-world scenarios.

Handling Failures is easier to implement in a simulation or virtual experiment where neither living beings nor objects can be harmed. Virtual or augmented reality is planned to be used to show the differences or similarities of models and reality, as already been implemented in [23] for the derivation of fundamental equations in fluid mechanics.

The use of laboratory equipment such as remote and virtual [24] or even the use of augmented reality laboratories [25], [26] is a direct way to address the learning outcome *Using Instruments*. The use further enables the students to self-directed learning as they are able to select laboratory experiments depending on a certain learning outcome they would like to achieve (*Working Mindset*). As especially in ultra-concurrent remote laboratories or virtual laboratories there is neither a time limit for experimenting nor a fixed date, students have enough time to explore and try things out (*Explorative Learning*). This is limited, however, by the fact that no real laboratory objects can be used in an arbitrary way.

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