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Integration of Learning Outcomes for STEM Laboratories into a New Learning Outcome Catalogue

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***Abstract*—Learning outcomes play an important role in education. For laboratory education in STEM, a multitude of different collections for programme level laboratory learning outcomes exist. This work has two major contributions: 1. a comparison of the different programme level learning outcome collections applying qualitative content analysis; and 2. a synthesis of a catalogue of 16 programme level learning outcomes for educational STEM laboratories based on the comparison. By including some more general frameworks – namely the Stifterverband Future Skills framework and the World Economic Forum Education 4.0 framework – we aim for a wider point of view that respects not only Academia but also economic perspectives while at the same time consolidating different perspectives and nomenclatures. We hope that the catalogue can both be useful for practitioners as well as for research in the area of laboratory pedagogy.**

***Index Terms*—Laboratory Education, Learning Outcomes, Literature Survey, Outcome-Based Education, Qualitative Content Analysis, STEM Education**

I. Introduction

Learning outcomes, in all their different shapes and sizes, play an important role in pedagogy. For example, one part of the *Bologna Process*, a large restructuring of the education system in the European Union, was to define every course / module through their learning outcomes [1, p. 12], [2]. The concept of learning outcomes[1] for European higher education was first discussed in the *2003 Berlin Communiqué*, an artefact of the *Bologna Process* [3], however the notion of finding a common language goes back at least to the late 1940s (see [4, p. xxvii, p. 12]) with the original Bloom's Taxonomy [5] ostensibly being one of the most influential models worldwide [4, p. xxi] (see also [1, p. 26]).

The laboratory as a place for learning has a long history, dating back to the 19th century with laboratory learning outcomes dating back to the 1970s [6]. Maybe one of the most important collections of learning outcomes for laboratories was developed at a colloquy in January 2002, where participants from multiple engineering subdisciplines developed a list of 13 programme level learning outcomes over three days [7]. A final version of these programme level learning outcomes for laboratories can be found in Feisel & Rosa [8]. In the last years, a multitude of programme level learning outcome collections for laboratories were developed (e.g., [9]–[13]).

Biggs & Tang differentiate three levels of learning outcomes: *institutional* level for outcomes that define graduates of a given institute of higher education; *programme* level for outcomes that define graduates of a given field of study, and *course* level outcomes for outcomes of a certain course [14, ch. 7]. Note that the expression *learning outcomes*, in this paper at least, is meant to address the general notion of learning outcomes while we use *programme level outcomes* in accordance to Biggs & Tang for specific learning outcomes students should achieve over the course of their studies.

All of these taxonomies have different scopes and dimensions. We believe that it would be useful to have one central definition of programme level learning outcomes which unifies the different approaches. Therefore, this paper aims to take different taxonomies into consideration and collate them

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[1]The corresponding Bologna document explicitly mentions the description of *"qualifications in terms of workload, level, learning outcomes, competences and profile"* [3, p. 4].

into one combined catalogue of programme level learning outcomes for STEM laboratories. We hope that collating the different taxonomies and making our mapping transparent we can facilitate a more consistent use. While this set can not – by definition – be complete or encompass all learning dimensions, we hope that it will still be useful when developing laboratories that are intended for use in STEM education.

II. Method: Qualitative Content Analysis

To develop a catalogue of programme level learning outcomes we followed the eight step qualitative content analysis process according to Mayring [15]. This process is a collection of techniques used to extract usable information from qualitative material such as text, e.g., interviews or open surveys but also can be applied efficiently to large document corpora [15].

Mayring [15] describes the eight-step method in-depth in chapters 8–15; in brevity, the steps may be summarized as:

- **Step 1: Forming the research question** defines a research question that is relevant either theoretically or practically.
- **Step 2: Establishing the theoretical background of the study** asks the questions of how the study fits into the current state of scientific knowledge as well as how the state of current knowledge influences the approach used for the study.
- **Step 3: Designing the study** creates the research plan, including the analysis of the qualitative material as well as ethical aspects.
- **Step 4: Gathering textual material, sampling** defines how the material is collected and pre-processed (e.g., transcription rules).
- **Step 5: Choosing and constructing adequate methods** chooses adequate methods for analysing the material.
- **Step 6: Conducting the study and presenting the results** is the step where (after preparing it in the previous steps) the study is conducted and the results of the study are discussed.
- **Step 7: Discussing quality criteria** discusses the quality of the study using various quality criteria.
- **Step 8: Reflecting on research implications** discusses which consequences can be drawn from the study.

To stay close to the outlined method, the implementation of the entirety of these steps for this study is described below in Sec. III.

We classify this paper as a literature survey according to Cooper [16] as follows: • **Focus**: theories • **Goal**: integration (generalization; conflict resolution) • **Perspective**: espousal of position • **Coverage**: central or pivotal • **Organisation**: conceptual • **Audience**: specialized scholars; general scholars; practitioners or policy makers

III. Results and Discussion

This section describes the implementation of the eight-step process of Mayring [15] introduced in Sec. II.

Step 1: Forming the research question:

The CrossLab project [17] is a large project developing cross reality laboratories for STEM education in Germany. The project spans multiple institutes from different backgrounds. One goal of the project is to create a unified pedagogical concept which all institutes can use for their (engineering) laboratories. In this concept, requirements for *Work 4.0* should explicitly be included. One part of creating this pedagogical concept is the creation of a catalogue of programme level learning outcomes which should be achieved by students during the course of their studies. Therefore, we define our research question as: **Which distinct programme level learning outcomes for laboratories exist in literature?**

Step 2: Establishing the theoretical background of the study

It is important to note that different models of learning outcomes exists (e.g., Bloom [4], [5] or SOLO [18]). At the same time, some papers use additional layers of abstraction – such as the differentiation between Bloom's *Cognitive*, *Psychomotor*, and *Affective* domains (see [5, pp. 7-8])[2]. However, such abstractions are used inconsistently across literature. This problem is compounded by differing nomenclature, e.g. while Feisel & Rosa [8, p. 127] define a programme level learning outcome called *Data Analysis*, Soll & Boettcher [13, p. 5] define a programme level outcome which is labelled as *Data Literacy*.

Due to this inconsistent usage of outcome models and abstractions we decided to work purely on the content of the programme level learning outcomes found in literature, focusing on the intent and description of a programme level learning outcome (e.g., not merely focussing on the label). When, for example, an item is called *Experimentation* and mentions the processing of data, we considered it to contain aspects of both *experimentation* and *data processing*.

Step 3: Designing the study

The study is a descriptive study according to Mayring [15, pp. 120-121]. It analyses programme level laboratory learning outcomes in literature. For this, we start with a deductive coding schema (based on Feisel & Rosa [8]) and extend it inductively to capture the programme level learning outcomes found in literature. Since the study only investigates published literature we do not expect any critical ethical aspects.

Step 4: Gathering textual material, sampling

To develop this catalogue, we started by identifying important works from literature. We identified several central or pivotal publications describing programme level learning outcomes for laboratories.

In addition to traditional engineering education, laboratories can be employed to prepare students for *Work 4.0*. For example, both Ortelt et al. [19] and Al-Zoubi et al. [20] argue that remote laboratories can teach important skills and prepare for *Work 4.0*[3]. Therefore, we consider it useful to widen the

[2]This is done, for example, in Nikolic et al. [11].

[3]For a good example of a remote laboratory for *Work 4.0*, see May et al. [21].

scope of considered works and also include programme level learning outcome collections focusing on Future Work, even if they do not relate directly to laboratories (e.g., [22], [23]).

We identified the following list of publications, which we considered relevant for our purpose:

- **Feisel & Rosa (2005) [8]:** This paper is a widely cited work in literature and can be considered as one of the most influential works concerning programme level learning outcomes for laboratories.
- **Soll & Boettcher (2022) [13]:** By using expert interviews with industry representatives, the paper adds a seldom investigated point of view.
- **Boettcher et al. (2023) [9]:** This paper is an attempt to extend the programme level learning outcomes of Feisel & Rosa [8] by experts in cross reality laboratory creation.
- **Sharma et al. (2022) [12]:** Sharma et al. investigate the efficacy of a remote design studio and present a set of extended programme level learning outcomes based on Feisel & Rosa [8] as well as the evaluation of those outcomes in the context of their laboratory.
- **Felder & Brent (2016) [10]:** Felder & Brent wrote a book about teaching practise in STEM. In chapter 4.8 (p. 84-86), they present their own interpretation of programme level learning outcomes based on Feisel & Rosa [8].
- **Nikolic et al. (2023) [11]:** Nikolic et al. analyse the importance of different programme level laboratory learning outcomes based on the *Laboratory Learning Objectives Measurement* instrument.
- **Future Skills (2021) [22]:** The German *Stifterverband für die Deutsche Wissenschaft* is a non-profit supporting research in Germany. It releases the so called *Future Skills* report, containing important skills and abilities to learn.
- **WEF Education 4.0 (2023) [23]:** The World Economics Forum is an organisation connecting experts in economics, politics, research, journalism, and more. This report contains skills and attitudes it considers important in future education.

Step 5: Choosing and constructing adequate methods

The coding schema started with the programme level learning outcomes of Feisel & Rosa [8], since those are either the basis of many works found or are explicitly mentioned in them. After that, we used an iterative approach where experts – that is, around ten researchers with each having several years' worth of experience in designing and conducting educational laboratories in STEM – from all four institutions of the CrossLab project [17] discussed how the newly found programme level learning outcomes aligned with the programme level learning outcomes currently considered. While doing this, an existing code might be redefined / extended (e.g., *Data Analysis* became *Handling Data* by adding aspects like archival or collecting) or a new programme level learning outcome might be added. This process continued until all experts agreed that all important aspects of the different taxonomies were covered.

Step 6: Conducting the study and presenting the results

Based on our approach, we derived a catalogue of 16 programme level laboratory learning outcomes. The comparison of all programme level learning outcomes can be found in Tab. I. To summarise the (new) programme level learning outcomes as well as the changed meanings of existing ones, we came to the definitions as given below:

1) **Instrumentation:** Students apply appropriate tools, such as actuators, sensors, controllers, or software, to solve a problem. Students learn and know about both commonly used and state-of-the-art technology.
2) **Models:** Students apply theoretical models to solve problems. They know the assumptions and limitations of models and can use that knowledge to choose the correct model.
3) **Experiment:** Students develop and conduct experiments. This outcome focuses on the procedure.
4) **Handling Data:** Students handle the different stages of data (collection, organisation, analysis, interpretation, archival).
5) **Design:** Students design (physical) artefacts. This outcome focuses on the final deliverable.
6) **Managing Failures:** Students handle problems, for example by giving and receiving criticism, handling bad experiment design, as well as dealing with failing equipment.
7) **Creativity:** Students use creativity for problem solving, for example by thinking outside the box.
8) **Psychomotor:** Students operate the required tools, including digital and cyber-physical systems.
9) **Safety:** Students know safety issues, perform risk analyses and establish safe environments.
10) **Communication:** Students communicate both in the laboratory as well as communicate the results of an experiment, both in speech and in text form. This includes giving helpful feedback.
11) **Teamwork:** Students work as a team and take different roles according to the needs of the team.
12) **Ethical Behaviour:** Students know ethical standards (including correct behaviour, sustainability issues or accessibility issues) and apply them while working both inside and outside the laboratory.
13) **Sensory Awareness:** Students use their senses to gather information.
14) **Context Expansion:** Students have knowledge[4] not confined to their own subject area but encompassing many different knowledge areas (including industry knowledge). This allows students to cooperate with different persons and enables them to access tool sets from disci-

[4]Knowledge as used in this specific programme level learning outcome does not refer to simply remembrance / recollection of facts, but to know subject areas as a whole and being able to act in them. See Bolisani & Bratianu [24] for a discussion about definitions of knowledge and the problem of capturing exactly what knowledge is.

plines beyond their own[5].

15) **Learning to Learn:** Students identify areas where they lack knowledge and engage in appropriate learning activities fitting their personal learning style.
16) **Personal Growth:** Students identify their own personal shortcomings and work on personal improvement. This includes getting to a working mindset[6] fitting their personality.

— **(Domain Knowledge):** This item is no programme level laboratory learning outcome, but is used in our catalogue as a placeholder for all discipline specific learning outcomes of the laboratory. It can therefore not be generalised across all laboratories. Since the content of the laboratory might be seen as important as any general laboratory skills, domain knowledge is kept in the catalogue as an unnumbered item for completion.

Notably, avid readers might find the first 13 items in this list at least somewhat familiar, as the paper by Feisel & Rosa [8] was the point of origin not only for our endeavour, but seems to be a trend in literature dealing with programme level laboratory learning outcomes (e.g., from our analysed papers: [9]–[12]). However, some of the stipulated programme level learning objectives from Feisel & Rosa [8] were extended for this catalogue, e.g., their *Objective 4: Data Analysis* was extended to *Handling Data* to better represent the added aspects of data gathering and archival. Others, like *Objective 2: Models*, were completely overhauled (even though the name was kept). To respect their work as base for ours, we decided to keep the first 13 items in the same order as they were in the source material.

What sets these results apart from a pure re-wording and re-confirmation of the original Feisel & Rosa objectives [8] is the additional inclusion of programme level learning outcomes 14-16, which were identified in [9] and [13], but can also be found in and confirmed within the Future Skills framework [22] and the WEF Framework for Education 4.0 [23], which highlights the importance of these programme level learning outcomes for *Work 4.0*. Sharma et al. [12] also touch upon programme level learning outcome 15 with their Objective 17, as seen in Tab. I.

One additional mention is the inclusion of *Domain Knowledge*, i.e., learning outcomes that are specific to the discipline or topic of the laboratory and deal with the laboratory's content, rather the general working skills as described in this paper. These are mentioned both in [13] and [23] and should be included for completion's sake.

Step 7: Discussing quality criteria

Due to the iterative and qualitative nature of this work and the inclusion of members from all four institutions of the CrossLab project [17] as well as the collaborative discussions around each item / term / wording, the design process can be considered a form of both **communicative validation** at the teacher level and **face validity**[7]. However, this also means that calculating classical validity criteria like stability or reproducibility [15, pp. 117-178] is not possible in this approach since all possible coders were already involved in the process and the number of papers was too small to split into multiple groups.

Step 8: Reflecting on research implications

In their work, Feisel & Rosa [8] indicate that the programme level learning outcomes for laboratories should be achieved during the complete undergraduate curriculum[8]. We agree with that statement and transfer it to our catalogue of programme level learning outcomes. This means that a singular laboratory does not need to address all these outcomes together but students should achieve these outcomes over the course of their studies. This aligns with Biggs [14, p. 125] stating that a course should not address more than five to six programme level intended learning outcomes.

The catalogue of programme level learning outcomes – as presented above – is in principle not bound to any concrete pedagogical theory. To show this, we want to show a few examples in this section on how to use them in different pedagogical theories.

SOLO Taxonomy. The SOLO Taxonomy (Structure of the Observed Learning Outcome) by Biggs & Collins [18] describes how well students can handle more complex tasks as their understanding of a topic increases. The taxonomy itself features five distinct levels [26][9]:

i) **Prestructural**: Students do not understand the topic of a task.
ii) **Unistructural**: Students understand few (isolated) aspects of a task.
iii) **Multistructural**: Students understand several aspects of a task, however these aspects are not yet connected.
iv) **Relational**: Students can connect aspects of a task and thus get a picture of the whole task.
v) **Extended abstract**: Students understand the task at an abstract level and can both reflect on the task itself as well as transfer the knowledge to new areas.

Chan et al. [27] showed that the taxonomy can be applied to different subject areas and students of different levels and is especially good at measuring student's critical thinking. However, one criticism raised by Chan et al. [27] was that that the taxonomy has some ambiguity where different persons

[5] One could argue that content expansion is not a programme level learning outcome that is addressable in a unit or course directly, but instead an emergent attribute students show by achieving different programme level learning outcomes in different laboratories. Still, we believe the concept of context expansion is important and thus deserves a place in our catalogue.

[6] Examples of which can be found in [13, pp. 4-5].

[7] For more details about face validity see [25].

[8] This is indicated at the start of their programme level learning outcomes, where it is mentioned explicitly that they are terminated by *"[...] completing the laboratories in the engineering undergraduate curriculum, [...]"* [8, p. 127].

[9] Biggs & Tang describe the levels as being hierarchical, e.g. a student that gives a multistructural response has a deeper understanding of a topic than a student giving a unistructural response [14, p.123].

reported the same response at vastly different levels of the taxonomy[10].

For every one of our 16 programme level learning outcomes, we can now define different activities[11] which students can be observed at to demonstrate the programme level learning outcome on a specific level. Since the programme level learning outcomes 1 - 13 are close to Feisel & Rosa [8] and already widely used in one form or another, we will focus here on the remaining three programme level learning outcomes. Note that Biggs deems prestructural understanding to be an unsatisfactory outcome (relating it to a failing grade) and himself doesn't list a corresponding "*quality of performance*" [26, pp. 352-353], hence it is not listed here.

14) Context Expansion:

ii) **Unistructural:** Students state companies that use the given methods/technologies.
iii) **Multistructural:** Students know all the steps that that are necessary to perform before and after an experiment.
iv) **Relational:** Students know how a method/technology fits into a production line.
v) **Extended Abstract:** Students can discuss shortcomings and limitations as well as advantages of a given technology or method for a given application.

15) Learning to Learn:

ii) **Unistructural:** Students know one or two learning technique(s) they regularly employ.
iii) **Multistructural:** Students know several different learning techniques.
iv) **Relational:** Students switch between several different learning techniques depending on the learning setting.
v) **Extended Abstract:** Students know how to identify and fill their knowledge gaps by using appropriate tools and techniques.

16) Personal Growth:

ii) **Unistructural:** Students identify one attribute of themselves that qualifies them for a given profession.
iii) **Multistructural:** Students identify a profession suitable for their specific set of skills and interests.
iv) **Relational:** Students explain why a certain soft skill is important for their profession.
v) **Extended Abstract:** Students transfer the skills learned in one context to tackle tasks in different contexts.

[10]Chan et al. [27] suggested that ambiguity could be reduced by using sub-categories, however even with sub-categories the problem is not solved.

[11]In our understanding, SOLO focuses on the level of understanding like in [27] instead of specific activities. There are some publications which assign verbs to specific levels (e.g., [14, pp. 90-91 , pp. 122-124]), however we do not follow these assignments for our examples since (in our opinion) focusing on understanding is more important than specific activities.

Instructional Design. Instructional Design, as defined by Reigeluth & An [28], is an approach for designing and evaluating instruction (in both formal and informal settings) by combining *learning science* with *instructional science*. It can be seen as an engineering process to creating instructions [29]. In general, Instructional Design consists of three steps [28]: i) define the problem ii) determine what needs to be taught iii) find the best method for teaching the content. There is some criticism levelled at instructional design since the usage of theory by practitioners is not always as desired [30], [31]. In addition, the adoption of Instructional Design seems to be decreasing [32].

One relatively new and comprehensive implementation of Instructional Design is *The Holistic 4D Model* by Reigeluth & An [28][12], which we use to demonstrate how our catalogue can be used in conjunction with Instructional Design. The model proposes a four-stage process where all stages in themselves feature iterative development processes [28]:

i) **Define**: In this step, the performance gap of the target audience and the need for instructions are determined. The instructional design project is planned.
ii) **Design**: Based on learners, resources, and contexts, design decisions about what to teach an how to teach are made. This can involve multiple levels (top level, mid level, lower level) if needed.
iii) **Develop**: Based on the results of the design stage, teaching scripts and learning materials are developed.
iv) **Deploy**: Finally, the instructions need to be implemented into the concrete system (e.g., school, workplace or informal learning environment). This stage includes a summative evaluation.

Hence, learning outcomes in general are especially relevant as context parameters for the **define** stage: a formalisation of the desired performance (in the form of learning outcomes) facilitates a quantification of the performance gap (by comparing intended learning outcomes against evident skills of the target audience), thus highlighting the aspects of instruction that need to be focused on.

We can answer questions like *"What does excellent performance look like?"* [28, p. 25 Table 2.1] or *"Do they have the knowledge and skills needed for effective performance?"* [28, p. 25 Table 2.1] since the catalogue contains programme level learning outcomes students should have achieved the end of their study[13]. Notably, Reigeluth & An refer to hypothetical employees in [28, p. 25 Table 2.1], but this can be applied to students analogously. However, this does not answer all questions of the performance analysis since questions like *"Is workload distributed fairly?"* [28, p. 25 Table 2.1] need other tools.

[12]For a brief overview over which Instructional Design models are currently used see [33].

[13]As mentioned at the beginning of *Step 8*, not every course needs to address all programme level learning outcomes at once. However, each learning outcome should be featured somewhere in the STEM study programme.

Bloom's Taxonomy. Bloom's (Cognitive[14]) Taxonomy was first described in [5] and redefined in Anderson et al. [4] / Krathwohl [37]. It consists of different different levels a skill might be taught[15], namely i) Remember ii) Understand iii) Apply iv) Analyse v) Evaluate vi) Create. Although there is an order of increasing complexity, they is no strict hierarchy and levels may overlap each other [37, p. 215]. The taxonomy can be combined with frameworks like *Constructive Alignment* [26].

For completion's sake, it should be noted that Bloom's taxonomy is not beyond scrutiny. For example, Crossland [38] poses the question whether Bloom's Taxonomy holds up taking newer findings from neuroscience into consideration. Masapanta-Carrión & Velázquez-Iturbide [39] investigated the use of both versions of Bloom in Computer Science Education. There, the authors found four general issues with both versions of the Bloom taxonomy: difficulties classifying learning goals, difficulties specifying the related knowledge, difficulties measuring the progress of students, and difficulties in understanding of the taxonomy itself. One of the authors elaborates on the last issue some years later [40] by identifying issues with the wording of the taxonomy, which makes classification of learning outcomes difficult and replication of classification efforts nigh-impossible (to some extent then defeating the purpose of a taxonomy altogether).

Some examples of how the different levels of Bloom's Taxonomy according to Anderson et al. [4] / Krathwohl [37] can be filled with specific activities corresponding to the programme level learning outcomes 14-16 are as follows:

14) Context Expansion:

i) **Remember:** Students describe the steps that must happen before and after an experiment (e.g. preparation and disposing of chemicals).
ii) **Understand:** Students explain the role of their anticipated work in a company.
iii) **Apply:** Students communicate with persons outside of their knowledge domain about an experiment.
iv) **Analyse:** Students identify how changes in the laboratory process (e.g. changing material in production) have an impact on other parts of a company.
v) **Evaluate:** Students conclude how an experiment can be changed to minimize environmental impact.
vi) **Create:** Students manage an interdisciplinary team in a project.

[14]Bloom [5] mentioned three Taxonomies for different types of competences: Affective, Cognitive, and Psychomotor. However, this specific volume focuses chiefly on the Cognitive domain. For the Affective Domain, see [34]. For the Psychomotor Domain, see [35] or [36] – both of which have nothing to do with the original 1956 group but are referenced by Anderson et al. [4].

[15]As a matter of fact, Anderson et al. [4] and Krathwohl [37] define two dimensions: The *Knowledge Dimension* classifying the type of knowledge and the *Cognitive Process Dimension* classifying the act that the knowledge is used with. This section will focus on the *Cognitive Process Dimension*. The *Knowledge Domain*, according to [37], consists of Factual Knowledge, Conceptual Knowledge, Procedural Knowledge and Metacognitive Knowledge. Both domains span open a 6x4 table of possible learning levels, see [37, p. 216, Fig. 1].

15) Learning to Learn:

i) **Remember:** Students name different learning activities.
ii) **Understand:** Students discuss which learning activity is best in which setting.
iii) **Apply:** Students use an appropriate learning activity for laboratory preparation.
iv) **Analyse:** Students determine which learning outcomes of a course they already can fulfil.
v) **Evaluate:** Students evaluate where they lack knowledge.
vi) **Create:** Students autonomously acquire knowledge from new areas outside their study programme.

16) Personal Growth:

i) **Remember:** Students recall soft skills important for their profession.
ii) **Understand:** Students explain why a certain soft skill is important for their profession.
iii) **Apply:** Students use predetermined soft skills in a given situation.
iv) **Analyse:** Students identify which soft skills are important in situation.
v) **Evaluate:** Students evaluate which of their own soft skills need improvements.
vi) **Create:** Students learn autonomously or improve a soft skill.

IV. Conclusion

This work presents a catalogue of 16 programme level learning outcomes combined from literature applying qualitative content analysis. As mentioned, we are aware that our proposed set of programme level learning outcomes is probably not entirely complete. Moreover, it will need to be revised some time in the future as demands from society and the economy towards students change. Nonetheless, we believe this to be a step in the right direction, especially as, to the best of our knowledge, neither the Future Skills framework [22] nor the World Economic Forum framework [23] have been included in thorough scientific dialogue as of yet. Including their perspectives in a generalised catalogue brings with it the benefit that implementing the catalogue lets one rightly assume that their students are well-equipped for both research as well as the working world.

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TABLE I: Aggregation of high-level learning outcomes from literature.

Learning Outcome	**Feisel & Rosa (2005) [8]**	**Soll & Boettcher (2022) [13]**	**Boettcher et al. (2023) [9]**	**Sharma et al. (2022) [12]**	**Felder & Brent (2016) [10]**	**Nikolic et al. (2023) [11][16]**	**Future Skills (2021) [22][17]**	**WEF Education 4.0 (2023) [23]**
– 1. Instrumentation	– Objective 1: Instrumentation	– Using Instruments		– 1: Instrumentation – 6: New Technology – 10: Accessibility	– 2. Instrumentation	– C1 – P2H – P2S – P6H – P6S – P7	– Software Development (Softwareentwicklung)	– Digital skills and programming
– 2. Models	– Objective 2: Models	– Know Difference Between Theory and Practice		– 2: Models	– 4. Modeling	– C2 – C9		– Critical thinking – Problem solving – Systems analysis
– 3. Experiment	– Objective 3: Experiment	– Explorative Learning		– 3: Experiment	– 1. Experimentation	– C3 – C4 – C9 – P3 – A1 – A6 – A7		
– 4. Handling Data	– Objective 4: Data Analysis	– Data Literacy	– ILO 20 to organize and manage data with new methods	– 4: Data Analysis	– 1. Experimentation	– C5 – C7 – C8	– Data Analytics & AI (Data Analytics & KI) – Digital Learning (Digital Learning)	
– 5. Design	– Objective 5: Design	– Know Difference Between Theory and Practice		– 5: Design		– C2 – P4 – A5	– User-centric design (Nutzerzentriertes Design) – Hardware / Robotics R&D (Hardware-/Robotikentwicklung) – Quantum Computing (Quantencomputing)	– Digital skills and programming
– 6. Managing Failures	– Objective 6: Learn from Failure	– Handling Failures		– 11: Learn from Failure	– 3. Troubleshooting	– P5 – A6 – A7		– Growth Mindset
– 7. Creativity	– Objective 7: Creativity		– ILO 17 to think out of the box	– 12: Creativity	– 5. Self-directed and creative thinking	– A3 – A5	– Problem solving skills (Lösungsfähigkeit) – Creativity (Kreativität) – Ability to Innovate (Innovationskompetenz)	– Creativity

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– 8. Psychomotor	– Objective 8: Psychomotor	– Using Instruments	– ILO 19: to work with cyber-physical systems	– 8: Psychomotor		– P1 – P2H – P2S – P3 – P4 – P6H – P7	– Software Development (Softwareentwicklung) – IT Infrastructure (IT-Architektur) – Quantum Computing (Quantencomputing)	– Digital skills and programming – Balance, coordination, positional awareness, strength
– 9. Safety	– Objective 9: Safety			– 13: Safety	– 6. Responsibility	– C6		
– 10. Communication	– Objective 10: Communication	– Writing / Documentation skills		– 14: Communication	– 7. Communication	– C8 – C9 – A2 – A4	– Digital collaboration (Digitale Kollaboration) – Intercultural Communication (Interkulturelle Kommunikation)	– Communication
– 11. Teamwork	– Objective 11: Teamwork	– Teamwork	– ILO 14 to develop personality	– 15: Teamwork	– 8. Teamwork	– A1 – A2	– Digital collaboration (Digitale Kollaboration) – Agile Methodology (Agiles Arbeiten)	– Collaboration
– 12. Ethics in the Laboratory	– Objective 12: Ethics in the Laboratory		– ILO 16 to develop critical thinking and acting sustainably	– 7: Sustainable development – 10: Accessibility – 16: Ethics in the Laboratory		– C9 – A4	– Digital Ethics (Digital Ethics) – Ability of Judgement (Urteilsfähigkeit) – Ability to Innovate (Innovationskompetenz)	– Civic responsibility – Environmental stewardship
– 13. Sensory Awareness	– Objective 13: Sensory Awareness			– 9: Sensory Awareness		– P1 – P5		

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Learning Outcome	**Feisel & Rosa (2005) [8]**	**Soll & Boettcher (2022) [13]**	**Boettcher et al. (2023) [9]**	**Sharma et al. (2022) [12]**	**Felder & Brent (2016) [10]**	**Nikolic et al. (2023) [11][16]**	**Future Skills (2021) [22][17]**	**WEF Education 4.0 (2023) [23]**
– 14. Context Expansion		– Know Industry Environment – Overview Over Larger Context	– ILO 17 to think out of the box				– Digital Literacy (Digital Literacy) – Ability of Judgement (Urteilsfähigkeit) – Ability to Innovate (Innovationskompetenz) – Change Management (Veränderungskompetenz) – Conflict Management (Dialog- und Konfliktfähigkeit)	– Negotation – Socio-emotional awareness – Civic responsibility – Environmental stewardship – Empathy and kindness – Global citizenship
– 15. Learning to learn		– Explorative Learning	– ILO 15 to improve one's style of learning – ILO 18 to develop self-directed learning skills	– 17: Engagement and learning			– Digital Learning (Digital Learning)	– Curiosity – Growth mindset
– 16. Personal Growth		– Working Mindset / Soft Skills	– ILO 14 to develop personality – ILO 15 working mindset				– Enterpreneurship and Initiative (Unternehmerisches Handeln und Eigeninitiative) – Resilience (Resilienz) – Mission Orientation (Missionsorientierung) – Change Management (Veränderungskompetenz) – Conflict Management (Dialog- und Konfliktfähigkeit)	– Critical thinking – Problem solving – Negotiation – Socio-emotional awareness – Adaptability – Conscientousness – Grit – Initiative – Empathy and kindness
– — (Domain Knowledge)		– Knowledge-Based Outcomes						– Domain-specific skills

[16] The items of Nikolic et al. (2023) [11] are only referred to by their code due to space restrictions and readability.

[17] The Future Skills [22] items are unofficial translations made in best-effort by the authors of this paper (original wordings as stated in the source are kept in parentheses for reference).