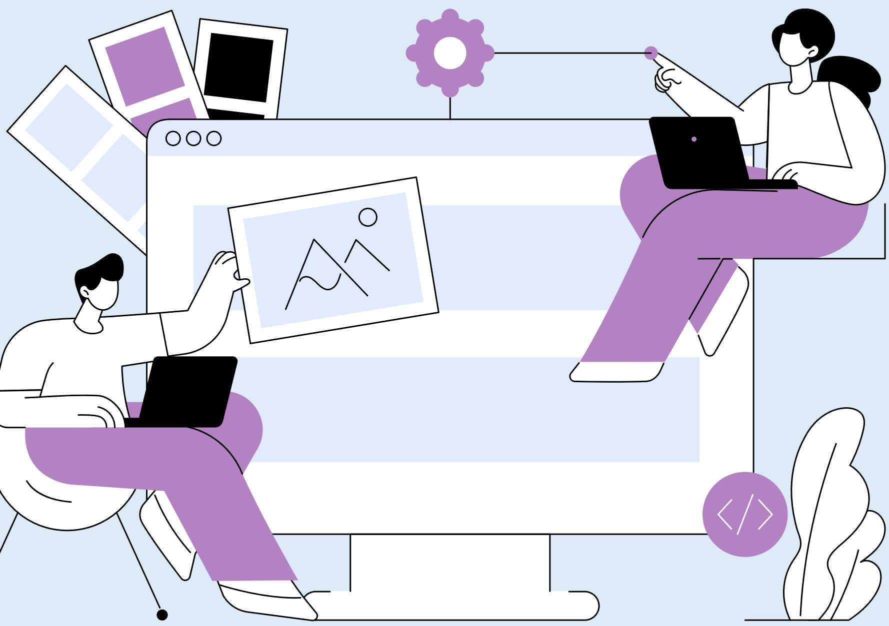
P4ELECS
Platform for Electrification Skills & Competences

Quicksheet

Designing Laboratory Sessions

Yousef Jalali, Annick Dexters, An Verburgh, & Greet Langie



Co-funded by the European Union

About

Laboratory teaching in science, engineering, and technical education is evolving. Traditional "cookbook-style" labs, often resource-intensive and highly scripted, are increasingly being reconsidered. Advances in educational technology, growing student diversity, and demands for efficiency and accessibility require a more intentional and aligned design approach.

This quick guide supports educators in designing laboratory sessions that:

- Promote deeper conceptual understanding
- Foster student agency, inquiry, and critical thinking
- Integrate professional and technical skills
- Optimize in-lab contact time through effective preparation and follow-up
- Align learning outcomes, teaching and learning activities, and assessment

The guide is grounded in principles of constructive alignment as articulated by John Biggs and Catherine Tang in Teaching for Quality Learning at University**.**

Three Guiding Questions for Lab Design

When designing or redesigning laboratory sessions, consider:

1. **What should students achieve?**
2. **How should teaching and learning activities be designed to support this achievement?**
3. **How should students be assessed to promote and measure learning?**

Each question corresponds to a core instructional design component.

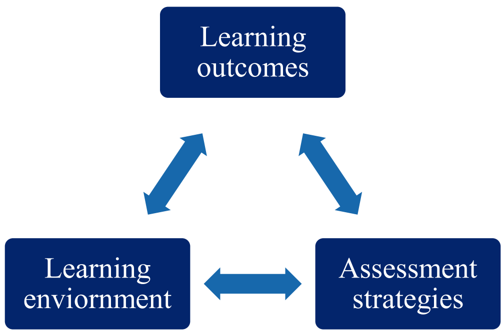


Figure 1. Core elements of constructive alignment

Corresponding section in document: Section 1: Learning outcomes; Section 2: Learning environment; Section 3: Assessment strategies

1. Defining Meaningful Learning Outcomes

Clear learning outcomes form the foundation of effective lab design.

Start with the End in Mind

For each laboratory session:

- Define **1–3 focused outcomes**
- Use action-oriented verbs consulting Bloom's taxonomy
- Ensure outcomes are specific and measurable
- Align them with appropriate qualification frameworks (e.g., EQF levels where applicable)

Learning outcomes should describe what students will be able to *do*, not merely what they will be exposed to.

Typical Laboratory Learning Outcomes

Laboratory sessions in HE and VET commonly aim to develop:

- Conceptual understanding of key and complex ideas
- Ability to design, modify, and troubleshoot experiments
- Technical and instrumentation skills
- Understanding of the relationship between theory and practice
- Recognition of the limitations of models and assumptions
- Communication of scientific or technical findings
- Effective teamwork and collaboration

✓ Target Higher-Order Thinking

Learning outcomes should extend beyond factual recall. Using Bloom's Taxonomy, ensure outcomes address higher cognitive levels such as: Analyzing, Evaluating, and Creating. Laboratories are particularly powerful environments for developing these higher-order skills when students are required to interpret data, justify decisions, critique limitations, and propose improvements.

✓ Consider Students' Prior Knowledge

Effective laboratory design requires understanding students' background knowledge and skills as well as their motivation and professional orientation. Activating prior knowledge before experimentation enhances engagement, reduces cognitive overload, and supports meaningful learning.

2. Designing the Learning Environment

Laboratory learning extends beyond the time students spend in the laboratory during scheduled contact hours. In addition to the explicit implementation of instructional design frameworks (can be referred to as **functional alignment**), it is also helpful to consider **structural alignment**, namely what students are expected to do across the three phases of a laboratory session: Pre-lab, In-lab, and Post-lab. Effective laboratory design integrates these three interconnected phases to support meaningful learning.

For the purpose of organizing this document, the three-phase model is discussed in this section (see **Figure 2 and Table 1**). For each phase, as illustrated in Figure 2, we highlight two keywords, among other relevant themes, to capture the essential focus of that phase.

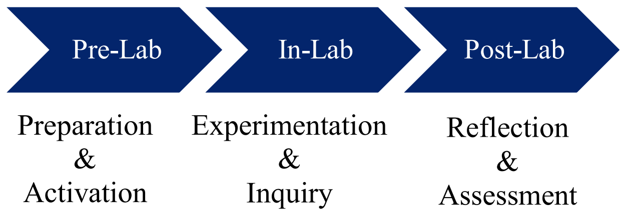


Figure 2. Three-phase model for designing lab

Table 1. Summary of instructional strategies across the three phases of laboratory activities

Phase	Purpose	Example Strategies	Instructor Tips
Pre-Lab	Prepare students for meaningful experimentation and activate prior knowledge.	• Short preparatory videos or readings • Concept mapping activities • Prediction tasks • Simulation exercises • Low-stakes quizzes	✓ Focus on conceptual preparation rather than procedural details. Students should understand the purpose and relevance of the experiment before entering the laboratory. ✓ Provide formative feedback. Pre-lab quizzes or tasks can serve formative purposes and may also count as low-stakes assessment to encourage preparation and engagement.
In-Lab	Promote active experimentation, student agency, and engagement with equipment, measurement systems, data, and peers.	• Predict–Observe–Explain (POE) activities • Guided inquiry tasks • Troubleshooting challenges • Peer discussion and collaborative problem-solving	✓ Encourage inquiry and student agency. Include open-ended challenges where students are asked to investigate and explain observed phenomena. ✓ Integrate technical content with professional skills, e.g., teamwork, planning, and communication skills.
Post-Lab	Provide opportunities for students to reflect on results, demonstrate achievement of the learning outcomes, and promote the transfer of learning to new contexts.	• Guided data interpretation and analysis • Reflection on results, limitations and uncertainty • Linking findings to theoretical models • Communication of findings	✓ Prompt reflection during and after experimentation: What do the results mean? Are alternative interpretations possible? What evidence supports different explanations? ✓ Design assessments that go beyond merely factual recall or basic understanding aiming to evaluate higher-level thinking.

3. Designing Assessment Strategies

The formulation of learning outcomes has direct implications for both the learning activities students undertake and the ways their learning is assessed. Assessment methods should therefore be **constructively aligned** with the intended learning outcomes and the level and type of engagement expected from students.

For example:

- If the goal is to assess basic understanding, students may be asked to explain how a system or component functions. This type of outcome can be assessed using formats such as multiple-choice questions or short written responses.
- If the intended learning outcome targets higher-order thinking (e.g., analysis or evaluation), assessment tasks should require students to explain **why** a system behaves in a particular way, predict system behaviour, or evaluate different explanations or limitations.

In other words, assessment task should reflect the complexity of the learning outcome.

✓ Choose Appropriate Assessment Formats

Multiple-choice questions can be useful for assessing lower-level learning outcomes. They can also help instructors quickly gauge students' **prior knowledge** and initial understanding. However, this format often restricts students' ability to demonstrate deeper reasoning and critical thinking. Instructors are encouraged to consult established resources on assessment design to ensure that questions are clearly formulated, conceptually meaningful, and aligned with the learning objectives. To assess deeper understanding, instructors should incorporate open-ended tasks that allow students to explain their reasoning. Developing deeper conceptual understanding in laboratory settings often requires students to engage actively with the material, explore alternative explanations, and seek additional information when needed. In this process, students may need to identify relevant learning resources and apply strategies for **self-directed learning**, which are important professional competencies fostered through the laboratory learning experience.

Assessing Practical and Professional Skills

While it is generally readable to define objective criteria for many **cognitive learning outcomes** (such as conceptual understanding), assessing **practical and professional skills** in laboratory courses can be more challenging. These forms of assessment often involve a degree of judgement, which can lead to perceptions of subjectivity if expectations are not clearly communicated.

One important learning outcome in laboratory education is the ability to **communicate technical findings effectively**, often through written laboratory reports.

To support fair and transparent assessment of written work, students should be informed in advance about the criteria used to evaluate their performance. Two commonly used tools are:

- **Checklists**, lists of evaluation criteria with associated point values.

- **Rubrics**, scaled rating systems with descriptive performance levels that help assess the quality of student work.

Using such tools helps make expectations explicit, supports consistent grading, and provides students with clearer guidance on how to improve their work.

✓ **Support Learning Through Assessment**

Effective laboratory courses balance formative and summative assessment and include:

- Low-stakes quizzes
- Draft submissions with feedback
- Peer review opportunities

Assessment should create learning opportunities rather than merely judge final performance.

Blended Laboratory Formats

Laboratory instruction today extends beyond purely physical spaces. Educators increasingly design across a spectrum of environments, from fully physical to fully virtual.

The concept of the **virtuality continuum**, introduced by Paul Milgram and Fumio Kishino (1994), helps conceptualize this spectrum.

- At one end: **Fully real environments** (traditional hands-on laboratories).
- At the other end: **Fully virtual environments** (computer-generated simulations, immersive VR).
- Between them: **Mixed Reality (MR)** environments, where real and virtual elements coexist.

Mixed Reality environments include **Augmented Reality (AR)** and **Augmented Virtuality (AV)**.

- **AR** enhances real-world environments by overlaying digital information in real time, for example by superimposing instructions, labels, or visualizations onto laboratory equipment through devices such as smartphones, tablets, or AR glasses.
- **AV** refers to predominantly virtual environments that incorporate elements from the physical world. In this context, a **digital twin** can be considered a form of augmented virtuality: students interact with a virtual model that is linked to a physical system.

It is important to note that the virtuality continuum was originally developed to classify visual displays rather than educational systems. As a result, some instructional formats do not fit neatly within the continuum. For example, **remote laboratories**, in which students access and control real equipment and obtain real data via the internet, are best understood as real environments mediated through digital interfaces and can therefore be positioned closer to the real end of the spectrum.

When intentionally combined, these laboratory modes can complement one another and enhance conceptual understanding. However, effective instructional design requires leveraging the **specific affordances of each medium**, rather than simply replicating the same activities across different formats.

Figure 3. Different modes of laboratory instruction (OpenAI, 2026)
The figure provides a simplified representation of learning environments positioned along varying degrees of integration between physical and virtual elements.

Final Reflection for Educators

When reviewing your laboratory session, ask:

- Are students merely following procedures, or are they thinking critically?
- Is assessment aligned with intended learning outcomes?
- Do pre- and post-lab activities support deep understanding?
- Is contact time used purposefully?
- Are different laboratory modes used strategically rather than conveniently?

Intentional design transforms laboratory sessions from procedural exercises into meaningful learning experiences.

Note on the Use of AI

AI tools can support the redesign and preparation of laboratory sessions. They can assist with:

- Aligning learning outcomes, activities, and assessment
- Generating reflective questions
- Exploring blended or immersive technologies
- Brainstorming engaging lab scenarios

When using AI:

- Provide sufficient contextual information about your course and students
- Critically evaluate outputs
- Adapt suggestions to your pedagogical goals

AI should support, and not replace, informed instructional design decisions.

References and Further Reading

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives: complete edition*. Addison Wesley Longman, Inc.

Biggs, J., & Tang, C. (2007). *Teaching for quality learning at university.* New York: McGraw-Hill.

Feisel, L. D., & Rosa, A. J. (2005). The role of the laboratory in undergraduate engineering education. *Journal of engineering Education*, *94*(1), 121-130.

Felder, R. M., & Brent, R. (2024). *Teaching and learning STEM: A practical guide*. John Wiley & Sons.

Jalali, Y., Langie, G., Verburgh, A., & Dexters, A. (2025). Designing Laboratory Sessions in Science and Engineering: A Holistic Framework and Guiding Questions, *SEFI 2025-53rd Annual Conference of the European Society for Engineering*.

KU Leuven Learning Lab (2024). KU Leuven, https://www.kuleuven.be/english/education/leuvenlearninglab/support/quick-guide-blended-course-design/design-your-course

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems*, *77*(12), 1321-1329.