Assessing Laboratory Learning

Overview

The laboratory is a unique learning environment that enables and consolidates "learning through doing". Assessing this learning can enhance students' conceptual understanding of the theory–practice relationship, their higher level reasoning skills and the development of their practical competence in laboratory work.

It is important that you clarify the specific objectives of the laboratory context for learning, for both students and assessors. These objectives should form the basis for all assessment decisions made. Learning outcomes that can be assessed using laboratory work include:

- technical and manipulative skills in using laboratory equipment, tools, materials, computer software
- an understanding of laboratory procedures, including health and safety, and scientific methods
- a deeper understanding of abstract concepts and theories gained by experiencing and visualising them as authentic phenomena
- the skills of scientific enquiry and problem-solving, including:
    - recognising and defining a problem
    - formulating hypotheses
    - designing experiments
    - collecting data through observation and/or experimentation
    - interpreting data
    - testing hypotheses
    - drawing conclusions
    - communicating processes, outcomes and their implications.
- the complementary skills of collaborative learning and teamwork in laboratory settings
- understanding, and being prepared for, future possible roles in laboratory-based work.

When to use

Assessment by laboratory learning is appropriate in contexts such as:

- undergraduate and postgraduate coursework in which laboratory tasks are a key feature
- professional laboratory student placement programs (work-integrated learning)
- capstone courses in which students undertake major projects requiring laboratory-based work.

While laboratory learning is most strongly associated with science and engineering, many of the same concepts are relevant to other clinical disciplines, such as law, medicine, social work and psychology.

Benefits

Assessing laboratory learning shares some of the advantages of assessing authentic learning generally. Some of the benefits include that it:

- allows learners to extend and enhance their understanding of theoretical concepts by finding out how they operate in practical contexts
- gives learners self-confidence and a sense of achievement in successfully completing laboratory tasks
- provides opportunities for experiential learning through trial and error, which contributes to deeper understanding and reduces learner anxiety about making mistakes
- fosters learners' development of critical and independent reasoning through practical training in hypothesis testing, data collection and analysis
- encourages the development of interpersonal skills such as teamwork, peer teaching, negotiation and collaboration
- provides a relatively informal and collegial learning environment that makes it easier for quiet or shy students to contribute to learning activities
- develops the acquisition of specific skills and capabilities required in workplace settings relevant to the discipline
- allows teaching staff more opportunities to monitor learners in person and provide assistance and feedback that is timely and thus more educationally effective
- rewards responsible and ethical behavior, such as following safety procedures, helping others, punctuality and generally being a cooperative and reliable classmate
- where laboratory task design is more open-ended and flexible:
    - gives learners greater responsibility and autonomy in making decisions
    - increases motivation by allowing learners to follow personal interests and use their creativity.

Challenges

- In the laboratory, safety issues are paramount and operational costs high, especially in large undergraduate classes. Science and engineering educators may be reluctant to conduct assessments in the lab, preferring less risky formats, such as online quizzes and written reports of laboratory work.
- Students enrol in science-based courses for lots of different reasons. This can be challenging when you teach large undergraduate science and engineering cohorts. Many of your students won't be science majors, and

this will influence the learning objectives significantly, and may be difficult to accommodate when you assess laboratory-based learning.

- Assessment design can be a problem. Laboratory-based learning usually has wide-ranging objectives, spanning practical and motor skills, broader understanding of concepts and theories, and higher level thinking and reasoning skills of scientific enquiry. It's a challenge to devise assessment methods that capture student learning that:
    - is active (hands-on, motor skills) and reflective (post-hoc), and that
    - encompasses both tacit knowledge and knowledge that can be articulated more readily.
- Educators often consider the demonstration of basic practical skills in the laboratory to be a preliminary hurdle assessment (on the grounds of safety), but conducting such an assessment in a laboratory environment can expose students to risks and be a highly resource-intensive activity.
- Assessment in labs can be very time-consuming for students and staff, and resource-intensive. It can be difficult to keep assessment tasks well aligned. For example, although laboratory activities may be designed to foster independent and creative approaches to solving novel problems, the assessment tasks may be closed-ended and recipe-like, which limits their usefulness in assessing higher-level understanding and reasoning.
- Giving students the autonomy to design and carry out their own lab experiments creates many challenges and a heavy workload for technical and support staff, particularly in large classes.
- Assessments conducted in laboratories are typically confined to tightly time-limited sessions. This can disadvantage some students. Reasonable accommodations for students with disabilities can be challenging to arrange.
- Many students are reluctant to admit to mistakes, or to acknowledge that an experiment has failed, fearing that this will result in low grades. Unless you highlight the value of learning from both successes and failures, and reward such learning in assessment, students may be tempted to engage in fraudulent conduct. For example, they may alter experimental results to show a more successful outcome, or they may plagiarise.

Strategies

Align learning objectives with assessment

The objectives for laboratory-based learning are fundamental to shaping the assessment process and methods.

To help you develop assessment tasks, consider classifying laboratory-based learning activities in terms of the extent of student autonomy they require.

For example, when the objectives of laboratory-based learning are mainly to develop basic skills and techniques and support comprehension of key concepts through observation and manipulation, the degree of student control and autonomy in the design and carriage of the work to be assessed may be low.

It is important for learning and assessment, over time, to reflect a clear progression from controlled tasks with predictable outcomes to more open-ended ones.

In establishing the level of independence and autonomy expected of students to carry out an assessment task, you might use the rubric developed by Fay et al. (2007), both to clarify task requirements for students, and to develop the criteria for assessing task performance. The rubric distinguishes progressively higher levels of scientific enquiry.

Figure 1: Scientific enquiry rubric (Fay et al., 2007)

Level of enquiry	**Description**
0	The problem, procedure and methods for achieving solutions are provided to the student. The student performs the experiment and verifies the results with the manual.
1	The problem and procedure are provided to the student. The student interprets the data in order to propose viable solutions.
2	The problem is provided to the student. The student develops a procedure for investigating the problem, decides what data to gather, and interprets the data in order to propose viable solutions.
3	A "raw" phenomenon is provided to the student. The student chooses the problems to explore, develops a procedure for investigating the problem, decides what data to gather, and interprets the data in order to propose viable solutions.

You can associate laboratory-based learning with a wide range of possible learning outcomes, not all of which can be assessed directly. For example, you wouldn't normally assess increased interest and enjoyment in the subject as a result of more active, hands-on engagement, and increased motivation for learning, even though these outcomes might be highly desirable.

Most importantly, when you design assessment of laboratory-based learning, ensure that the intended learning outcomes shape the design. Clarify to students how you have aligned assessment methods with learning outcomes, to guide them in their learning. The ideal way to do this is by using an assessment rubric indicating how different levels of performance are graded.

Assess by direct observation

Structured mini-practicals are a simple, effective way to assess a wide range of skills. Students can undertake them as part of routine laboratory sessions. They are particularly effective in assessing students' manipulative, observational and interpretive skills.

When using observation assessment, follow a systematic plan or rubric. That way it's clear to both the assessor and the student what is to be observed and recorded. You can also use an oral assessment to supplement the observation, for example, to check a student's understanding of particular techniques.

Students often perceive assessment of mini-practicals in the laboratory as contributing positively to their learning. Make sure your design of mini-practicals doesn't get in the way of students demonstrating their skills and capabilities. For example, don't impose significantly tighter time limits than students are used to in non-assessable lab sessions.

Mini-practicals are ideal for developing and assessing group and teamwork skills. If any laboratory demonstrators are involved in assessment, give them clear guidance and support, as well as explicit assessment criteria to guide their judgments of students' performance.

Additionally, you can use both peer assessment and self-assessment. The course might also offer the opportunity to involve others in assessing by observation. You might, for example, want to invite experts to come to campus or accompany your class in fieldwork, professional or industry placement, or other forms of work-integrated learning.

You can assess practical skills using a mastery approach rather than by grading. For example, where laboratory work consists of a linear sequence of activities, students may be assessed as having completed each activity on the basis of an observed outcome that must be completed, recorded and checked off by the tutor or demonstrator before moving to the next activity. Their achievement of each staged outcome indicates their competence in the related practical skills.

Use this approach in the early stages of a course (or before a course has started) to ensure that students have foundational technical skills, which will enable them to fully participate in future laboratory classes. Require them to perform a number of essential laboratory activities that demonstrate their ability to operate within occupational health and safety regulations.

Use laboratory notebooks

Laboratory notebooks are a form of authentic assessment, as they replicate what scientists actually do. Students use the notebook - possibly electronic, as reported by Quinnell et al. (2009) - to record details of all the experiments students complete in the laboratory. Requiring students to record their laboratory methods and results as a running record of their laboratory work is a vital part of the "doing" of science; asking students to present these records periodically as part of the assessment of a course reinforces the value of documenting laboratory work.

You can assess the notebooks in different ways:

- demonstrators can assess them weekly in the laboratory
- they can be collected at random times to encourage students to complete them routinely, or

- students can be set an open-book exam using their notebooks to respond to questions based on their experiments.

Just as with other forms of assessment, make the assessment criteria explicit and teach students what constitutes a good notebook. Also make it clear what they should do if they miss an experiment, or if their experiment does not succeed. For example, if they use another student's data they must acknowledge this and explain the problem with their own experiment.

Use laboratory reports

Unlike laboratory notebooks, which are written while experiments are being conducted, laboratory reports are prepared on completion of an experiment. They can demonstrate students' observation, interpretation and reflection abilities, and you can infer from them the knowledge and skills developed through lab-based learning. Laboratory reports can involve a lot of work for both students and staff, sometimes entailing long delays between the student's submission of the report and the return of feedback and grades.

To reduce the workload, you might want to use report templates; students complete the templates during the laboratory session. You can have tutors mark some sections of the template to provide immediate feedback to the students, then leave time for students to complete interpretive and evaluative writing assessment tasks, in which they, for example, synthesise key findings from an experiment and relate them to published results.

Teach lab report preparation skills explicitly, and provide opportunities for practice. Use available resources such as the **WRISE (Write Reports in Science and Engineering) website**, and incorporate the structured development of students' communication competence as an explicit component of assessment tasks and marking criteria. Give clear instructions about the assessment task, along with explicit assessment criteria and unambiguous guidelines so that students know where to focus their efforts.

In laboratory reports, sometimes students report on methods they did not implement, or results they did not obtain. Address ethical issues as a central part of scientific enquiry, and ensure that assessment processes align with them. For example, an assessment exercise might require students to add a personal reflection on any ethical dilemmas they faced in carrying out their laboratory work and preparing their report.

To develop this type of assessment beyond the straight lab report, require students to:

- pitch their reports for different (imagined or real) audiences, for example, a government body or a local newspaper. To do this, students need to think about that audience, and consider the best way to interpret and present their results.
- prepare a set of instructions and some guidelines for others to carry out the same experiment they have just completed.

Use learning logs

Ask your students to keep a learning log as a way of reflecting on their own learning and progress. These logs can constitute a part of the assessment regimen. Students can record "critical incidents" at the time of their experiments, then reflect on and discuss these.

Make sure all tutors are clear as to which learning outcomes the journal-keeping is aligned with. Learning logs should not be just a record of routine activities, but should help students develop communication and critical skills.

Have students act as teachers

Sometimes the deepest formative learning happens when learners try to teach what they have learnt to a real novice, or someone acting as a novice.

This is particularly true in relation to practical skills. The new learner gains immediate feedback on their own understanding and capacity to explain, based on how quickly the novice picks up the skill being taught.

Summative assessment tasks can be developed from this principle. For example, a task requiring students to provide explanations and guidance about scientific concepts and/or practical skills for the next student group helps them revise their laboratory learning, and consolidate their understanding about the relationships between theory and practice.

They can deliver learning products as, for example, written instructions or guidelines, or audio or video recordings of laboratory demonstrations and other presentations. Assessment tasks like these are also ideal settings for reciprocal peer assessment and self-assessment, supported by assessment rubrics.

Conduct tests and quizzes

When you integrate "mini-tests" with laboratory work, students receive feedback on how well they understand the conceptual basis of their practical work. The results can inform subsequent teaching activities, for example by highlighting areas of common conceptual misunderstanding.

Hold poster sessions

Students can develop posters based on their experiments carried out; these allow you to assess their observational, analytical and communication skills, and encourage students to be creative and reflective. You can require that their poster production be a group project and/or link it to a presentation. Tutors and/or peers can assess the posters, giving the students fast, formative feedback.

When you set a poster task, give students clear instruction about the objectives, presentation formats and so on. Don't reduce poster session assessment simply to a competition with awards for the top few. Be prepared to give feedback that rewards students for the work they do and contributes to their learning.

An event where students present their posters can be an especially engaging assessment forum, offering students the opportunity to experience a mini-science conference.

Have the students give presentations

Students (in groups) can present an experiment or set of experiments to their peers and report findings, challenges and implications. If you can, incorporate these presentations into lab sessions, so that students learn about experiments from their peers. As with posters, you can use either peer or tutor assessment, or a combination of these.

Presentations can be pre-recorded by students, using basic available technologies such as mobile telephones, then uploaded to a shared online space. As an example, Pearce (2010) describes an assessment task that entailed students making a video recording of themselves narrating what they did in their last laboratory experiment.

Get students to complete projects

A project is a time-intensive task for students to complete and for teachers to assess. However, the use of projects for assessment can encourage deep learning and scientific enquiry.

Projects can integrate a range of practical skills and motivate students to explore new ideas and areas. The method reported by Ketpichainarong et al. (2010) outlines a staged approach:

- beginning with a given experiment for practice, then
- moving on to students designing and conducting their own experiment, with
- oral and written presentation of processes and outcomes supported by
- peer assessment and class discussion.

Make pre-laboratory work an assessment task

To help students prepare for, and make the most of, their laboratory learning experiences, have them undertake assessed pre-laboratory activities. These can also help you assess their experiment planning skills.

You might set students the task, in groups, of designing an experiment before going into the laboratory. Instruct them to use discussion forums or wikis so that you can track how their ideas develop and how each student contributes. Ask them to present their plan for experiment as a flowchart or graphic.

Then again, you could require students to carry out written pre-laboratory work, answering questions about the upcoming laboratory procedure. Over time, reduce the number of explicit, directed questions and indicate that students are expected to take greater responsibility for researching and writing up key aspects of the procedure.

You can use video recordings of laboratory activities or descriptions of experiments as resources for online quizzes that students must complete before laboratory session. Pre-laboratory work is also a way of addressing risk and safety issues.

Ensure fairness

Ensure that you accommodate students with disabilities, in any lab work. For example, you might engage an education support worker for a student with reduced mobility or colour-blindness. Work with the student to identify the best approach.

In planning for learning and assessment, accommodate any significant differences in the laboratory experience levels of students entering courses with laboratory-based components, to minimise the chance of unfairly disadvantaging them.

Use technology

Use virtual laboratories as part of pre-laboratory assessment, to familiarise students with laboratory safety. Or use them to replace real laboratory experiences, having students undertake experiments and analyse results. Remember, though, that certain aspects of learning can't be assessed in simulated environments, particularly tasks requiring touching, smelling, motor skills and so on.

Online laboratories or iLabs are experimental facilities that allow students and educators to carry out experiments from anywhere at any time. You can design a range of formative assessment activities based on the simulations available in these laboratories, and both students and teachers can monitor student understanding and progress.

Use technology to support the administration of assessment and reduce workload. For example, use smartphones to record students' laboratory assessment results in a central database during the laboratory session, and allow students to access their results and receive prompt feedback during or immediately after their laboratory session.

Additional information

External resources

- **ChemCollective**: a virtual chemistry laboratory
- **Physclips**: multimedia resources illustrating physics concepts developed at UNSW
- **WRISE (Write Reports in Science and Engineering)**

Further readings

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