Final report for eSTEeM project

Project Title: An investigation into the breadth of learning objectives and skills developed in OpenSTEM Labs experiments

Keywords: online laboratories, remote laboratories, virtual laboratories, OpenSTEM Labs, learning objectives

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1 Executive Summary

The OpenSTEM Labs (OSL) deliver authentic practical experiences to STEM students using real time instrumentation, data and equipment for practical enquiries over the internet. The OpenSTEM Labs is a major initiative at the Open University that is used across the STEM Faculty to deliver remote and virtual experiments to our distance learning students with some experiments also freely available to the public (Open University, 2021). The OSL now has more than 100 experiments across a wide range of subjects.

This project explores the breadth of learning objectives and skills developed in OpenSTEM Labs activities to help us to understand the learning that is developed in our existing activities and to aid the design of future activities.

The academic literature for remote and virtual laboratories was reviewed to clarify the terminology and understand the state of the art in the field. A classification scheme for remote and virtual experiments was then developed building on the findings of the literature review. The classification scheme was used to map a representative sample of OSL activities, providing a searchable database of activities. The database has given us a better understanding of the range of interaction types and learning objectives that are developed in OpenSTEM Labs activities. For example, highlighting differences in approach between different academic disciplines and identifying some gaps in coverage of learning objectives. The most common learning objectives were "develop subject knowledge and understanding" and "analyse and interpret data" and the least common were "identify and deal with health and safety issues" and "behave with high ethical standards".

In the future, the classification scheme and database will be useful for module teams in the early stages of module production to help them design practical activities that address a wide range of learning objectives or to search for existing activities that could meet their learning needs. A catalogue of OSL activities has also been created as an easy-to-read reference document.

2 Aims and scope of your project

The aim of this project was to gain a better understanding of the range of activities in the OSL and their educational learning objectives. The aims of the project are summarised below:

1. Perform a literature review of remote and virtual labs classifications and their learning objectives/ outcomes
2. Develop a classification scheme of types of remote and virtual laboratories building on taxonomies in the literature
3. Develop a classification scheme of learning objectives of remote and virtual laboratories building on existing schemes in the literature

4. Review the developed classification schemes in a workshop and revise based on feedback
5. Create a structured database template for remote and virtual laboratories using Microsoft Excel for use with OpenSTEM Labs activities
6. Define a process for mapping OpenSTEM Labs activities and recording the results in the database
7. Map a representative set of OpenSTEM Labs activities using the classification scheme
8. Analyse the mapping results to look for common themes and identify gaps
9. Consider how the mapping process could be applied at the learning design stage for future module production

3 Activities

This section reports on the key activities of the project and is divided into two main sections, firstly a literature review of previous research in the field including existing classifications for remote experiments and their learning outcomes and secondly the development of the classification scheme for OpenSTEM Labs experiments including a glossary of relevant terms from the literature.

3.1 Literature review

3.1.1 Background

Practical learning is an essential part of degree study for many STEM subjects and is usually delivered in face-to-face settings during timetabled laboratory sessions. The Open University has developed innovative approaches to deliver practical learning including home experiment kits and intensive residential schools. Rapid developments in internet technology have opened up new opportunities to provide practical learning through remote and virtual laboratories (de Jong, 2013; Hatherly et al. 2009) and these have been implemented both in distance learning and conventional settings. Remote and virtual laboratories have been proposed as a way to reduce the high costs of face-to-face laboratories and to support increasing student numbers while sharing specialised skills and resources, reducing overall costs and enhancing the student experience (Ma and Nickerson, 2006; Kennepohl, 2010; Waldrup, 2013, Sharples et al, 2015 Lynch & Ghergulesca, 2017). Since the start of the Covid-19 pandemic in 2019, many conventional universities have seen a rapid push towards remote and virtual laboratories in order to support students while their campuses were closed.

3.1.2 Definitions of online, remote and virtual laboratories

The terms online, remote and virtual laboratory are widely used in the context of laboratories for remote learners but are not always consistently applied. This section provides a brief review of the definitions from the literature and clarifies the terminology that will be used in this project.

3.1.2.1 Online Laboratories

Zutin et al. (2010) define online laboratories as "interactive experiments provided over the internet" and their definition encompasses all types of laboratory that are delivered online, including both remote and simulated experiments. Rivera and Petrie (2016) also state that online laboratories can "be either remote laboratories or virtual laboratories".

3.1.2.2 Remote Laboratories

Remote laboratories are defined by Rivera and Petrie (2016) as "real physical laboratories accessed through a network. Instruments can be accessed, monitored and controlled from a distance". Similarly, Orduna et al. (2016) refer to remote laboratories as "users using real physical equipment [remotely] in an interactive mode… or in a batch mode". Whilst the wording is different between the definitions, the basic principle is the same, that students connect remotely to real equipment. A selection of definitions of remote laboratories from the literature are presented in Table 1 and in this project we use Rivera and Petrie's definition of remote laboratories as, "*real physical laboratories that are capable of being accessed through a network.*"

3.1.2.3 Virtual/ simulated Laboratories

There are many definitions of virtual and simulated laboratories in the literature. Zutin et al. (2010) refer to virtual laboratories as "web-based software simulations" and (Rivera and Petrie, 2016, p14) define virtual labs as "simulations that mimic the behaviors of real laboratory artifacts". Ma and Nickerson (2006) refer to simulated laboratories as "imitations of real experiments [where] all the infrastructure required for laboratories is not real but simulated on computers. Reeves and Crippen (2020, p1) define virtual laboratories as "Virtual laboratories (V-Labs) are technology-mediated experiences in either two- or three-dimensions that situate the student as being in an emulation of the physical laboratory with the capacity to manipulate virtual equipment and materials via the keyboard and/or handheld controllers". The types of virtual/ simulated laboratories referred to are diverse and can include physics simulations, algorithms, datasets or immersive visualisation. Classifications of virtual/ simulated laboratories will be discussed in section 2.2.4. At the Open University, the terms "interactive screen experiment" (Hatherly et al., 2009) or "on-screen experiment" have previously been used to define a type of virtual laboratory that is "a computer-based activity where students interact with an experimental apparatus or other activity via a computer interface". In this project we will use define virtual laboratories as "*Imitations of real experiments [where] all the infrastructure required for laboratories is not real, but simulated on computers*" based on Ma and Nickerson's definition for simulated labs. Selected definitions of remote and virtual laboratories from the literature are presented in Table 1.

Table 1 Definitions of remote and virtual laboratories from the Literature

Topic	Author	Definition
Remote laboratories	Rivera and Petrie, 2016, p14	" Remote laboratories use real physical laboratories that are capable of being accessed through a network. The instruments can be accessed, monitored and controlled at a distance.."

	Orduna at al. 2016, p224	"Users using real physical equipment [remotely], in an interactive mode … or in a batch mode.
	Ma and Nickerson (2006, p6)	"..experimenters obtain data by controlling geographically detached equipment. In other words, reality is mediated by distance"
	Corter et al, 2011, p2055	Remotely-operated educational labs … offer students the ability to collect data from a real physical laboratory setup from remote locations … via web-based computer technology
	Zutin et al., 2010, p1742	Remote Laboratories "consist of real hardware equipment. …[that] allows persons to manipulate real hardware
Virtual/ Simulated laboratories	Ma and Nickerson, 2006, p6	"Simulated labs are the imitations of real experiments. All the infrastructure required for laboratories is not real, but simulated on computers."
	Rivera and Petrie, 2016, p14	Virtual laboratories… are basically simulations that mimic the behaviors of real laboratory artifacts
	Hatherly et al., 2009, p752	A virtual laboratory is a computer-based activity where students interact with an experimental apparatus or other activity via a computer interface.
	Corter et al., 2011, p2055	Simulations "offer another means of gathering data to illustrate course concepts and principles, but using data generated by a simulation model."
	Zutin et al., 2010, p1742	Virtual laboratories are "Web-based software simulations"

3.1.3 Classifications of Online laboratories

Several authors have created classification schemes for online laboratories that can be used to better understand the types of activity and interaction.

Zutin et al. (2010) developed a laboratory classification that divides online laboratories into remote, virtual and hybrid laboratories. Orduna et al. (2016) describe three models of online laboratory, (i) remote laboratories with "users using real physical equipment, in an interactive mode", (ii) datasets, where "data are gathered from previous experiments, which can be accessed and managed" and (iii) simulations which are "software systems that simulate the full environment on which the user adds some parameters and obtains a result". Reeves and Crippen (2020) describe another type of virtual laboratory as an "immersive visual environment" which they define as "technology-mediated experiences in either two- or three-dimensions that situate the student as being in an emulation of the physical laboratory with the capacity to manipulate virtual equipment and materials via the keyboard and/or handheld controllers". Selected definitions of subtypes of virtual laboratory from the literature are shown in Table 2 and a high level model of remote and virtual laboratories that will be used in this project is shown in Figure 1.

Table 2 – Definitions of subtypes of virtual laboratory from the literature

Topic	**Author**	**Definition**
dataset	Orduna et al., 2016	data are gathered from previous experiments, which can be accessed and managed

simulation	Corter et al, 2011	students gather data from a computer simulation model of an experiment
	de Jong et al., 2013	Laboratories where investigations involve simulated material and apparatus
	Orduna et al., 2016	Where all the results are calculated and not tested in a real environment (e.g., a physics simulator…)
immersive	Reeves and Crippen, 2020	Technology-mediated experiences in either two- or three-dimensions that situate the student as being in an emulation of the physical laboratory with the capacity to manipulate virtual equipment and materials
	Matchet, Lowe and Gutl, 2012, p531	Virtual worlds allow 3D contexts to be combined, which draw attention to behaviours that might vary from those predicted by a model

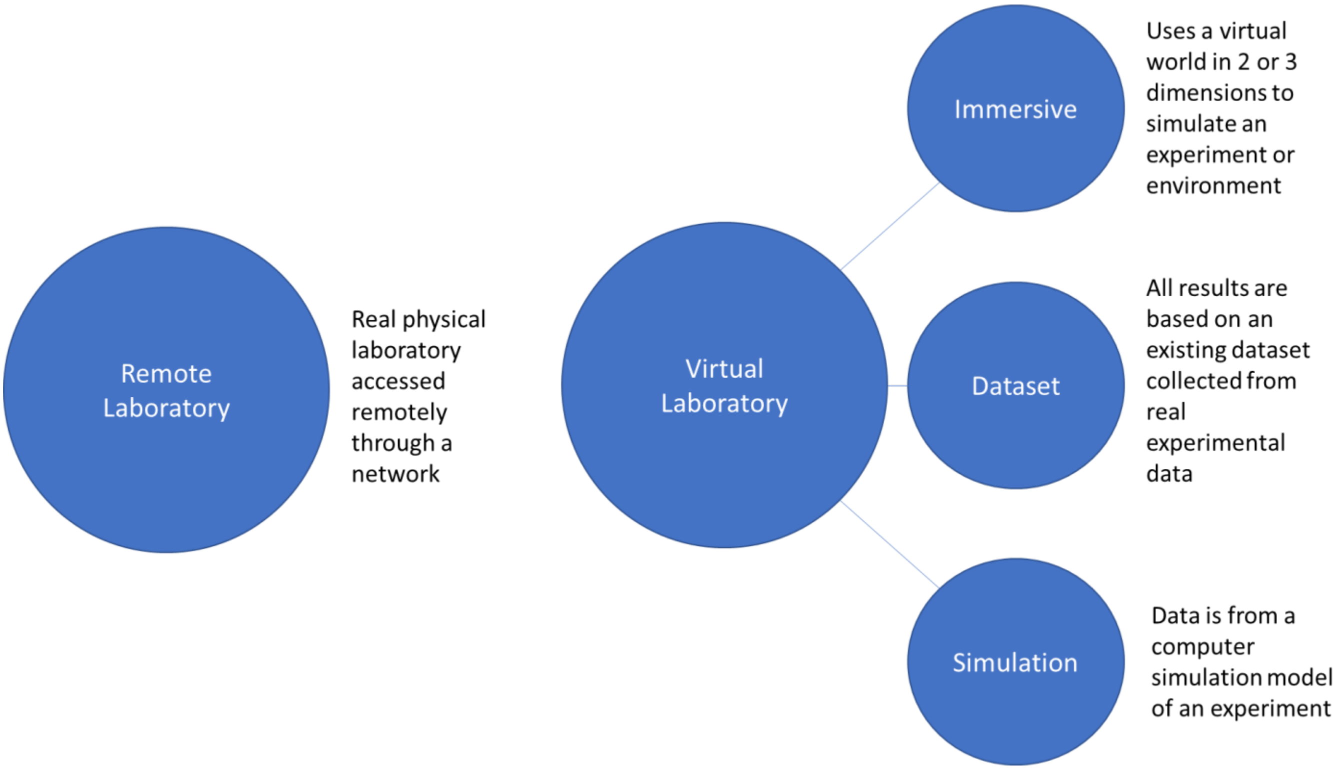


Figure 1 High level taxonomy of Online Laboratories.

Several authors classify online experiments by types of user interaction. Zutin et al. (2010) subdivide experiments into three types: observation experiments where the experiments only allow users to observe an experiment; fixed experiments where it is possible to control one or more measurement instruments remotely but the experiment environment is fixed, and adaptive experiments where the experiment parameters as well as the experiment environment are remotely changeable. Nickerson et al. (2007) created a model for investigating the relative effectiveness of hands-on, remote and simulated laboratories in education as shown in Figure 2. The model is used to compare the effectiveness of different laboratory types, considering both the experiment design and the student experience – measured through test scores and student motivation.

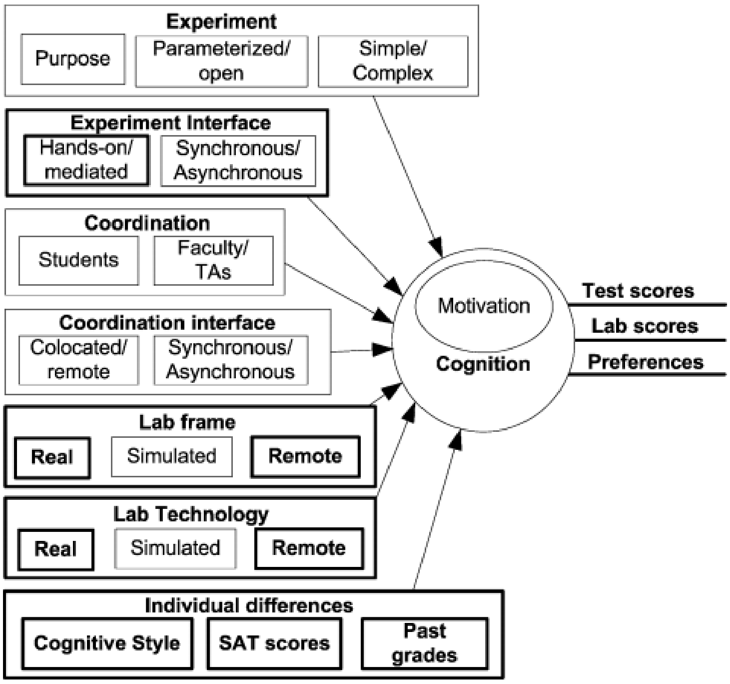


Figure 2. Model for investigating the relative effectiveness of hands-on, remote and simulated labs (Nickerson et al., 2007)

Trevelyan (2004) classifies remote laboratories in terms of the student interaction type, considering the level of interaction between the student and the experiment including queued batch, real-time experiments. This has some similarities to the synchronous/ asynchronous definition in Nickerson et al. (2007). Trevelyan et al. also differentiate between real time interactive experiments and real-time measurements without control. Table 3 summarises definitions of experiment interactions categorised into two main aspects – use mode and interaction type.

Table 3 Types of experiment interactions

Interaction type	**Sub-type**	**Authors**	**Definition**
Use Mode	**Synchronous**	Trevelyan, 2004	Real time interactive - the user can change parameters and observe results in real time.
		Orduna at al. 2016	users using real physical equipment [remotely], in an interactive mode
	Asynchronous	Nickerson et al., 2007	the ability to asynchronously run the experiment is convenient from a scheduling perspective
		Trevelyan, 2004	Queued batch- the user sets parameters and transmits a command to begin the experiment. There is no user interaction during the experiment.
		Orduna at al. 2016	Users using real physical equipment [remotely], … in a batch mode.
Interaction Type	**Observation**	Trevelyan, 2004	Real-time measurements without control - there is no need for the user to

			set controls except, perhaps, to select the measurements and data rate.
		Zutin et al., 2010	where the experiments only allows users to observe an experiment
	Interactive	Zutin et al., 2010	where it is possible to control one or more measurement instruments remotely but the experiment environment is fixed
	Open	Nickerson et al, 2007	depending on whether the problem, the method, and the answer are given
		Zutin et al., 2010	where the experiment parameters as well as the experiment environment are remotely changeable.

Based on the definitions identified in the literature we have created a glossary of terms that will be used to classify online experiments in this project (provided in Appendix 1). Having defined the types of online laboratories and the type of student interactions, the next step is to consider the range of learning outcomes/ objectives that can be addressed by these types of laboratories. The following section reviews the previous research into learning objectives and learning outcomes for online activities.

3.1.4 Classifications of Learning Objectives in Online Laboratories

Many researchers have classified learning outcomes and learning objectives that are developed in remote and virtual laboratories. Ma and Nickerson (2006) performed a literature review on the effectiveness of "hands-on, simulated and remote-laboratories" and developed a model for laboratory education that classified labs from the literature using four laboratory educations goals – conceptual understanding, design skills, social skills and professional skills. These educational goals are aligned to the ABET (Accreditation Board for Engineering and Technology) defined technical outcomes used for the accreditation of engineering courses in the United States.

Brinson (2015) developed a six-category tool for classifying intended outcomes for laboratory learning referred to as KIPPAS (Knowledge, Inquiry, Practical, Perception, Analytical, Social and scientific communication) as shown in Table 4. The tool is influenced by the eight essential practices of science and engineering as outlined by the US National Research Council and aimed to provide a common basis for comparing learning outcomes between different studies of learning outcomes for laboratories. Brinson claims that a benefit of their tool is that is incorporates the natural sciences as well as engineering by including inquiry and analytical skills. Brinson reports that remote and virtual laboratories are being used to develop a wide range of learning outcomes, most commonly developing 'knowledge and understanding' but less frequently developing 'practical skills'. He attempts to synthesise recent empirical learning outcome achievement between traditional and remote/ virtual labs and highlights that learning outcomes vary between studies. Brinson found that content knowledge was most frequently assessed, highlighting a gap in the assessment of practical skills developed during remote experiments.

Table 4. Brinson (2015) KIPPAS tool for classifying intended outcomes for laboratory learning

Knowledge and Understanding	The degree to which students model theoretical concepts and confirm, apply, visualize, and/or solve problems related to important lecture content
Inquiry skills	The degree to which students make observations, create and test hypotheses, generate experimental designs, and/or acquire an epistemology of science
Practical Skills	The degree to which students can properly use scientific equipment, technology, and instrumentation, follow technical and professional protocols, and/or demonstrate proficiency in physical laboratory techniques, procedures, and measurements
Perception	The degree to which students engage in and express interest, appreciation, and/or desire for science and science learning
Analytical Skills	The degree to which students critique, predict, infer, interpret, integrate, and recognize patterns in experimental data, and use this to generate models of understanding
Social and Scientific Skills	The degree to which students are able to collaborate, summarize and present experimental findings, prepare scientific reports, and graph and display data

Feisel and Rosa (2005) describe a set of 13 fundamental objectives of engineering instructional laboratories (shown in Table 5), which was developed by a group of engineering academics at a colloquy in 2002. They note that the learning objectives broadly fit into the three main domains of learning - cognitive, affective and psychomotor, but state that they have developed a more refined objectives set because “more specific objectives are needed to provide clear guidance in developing instructional laboratories”.

Table 5. Feisel and Rosa (2005) fundamental objectives of engineering instructional laboratories.

Instrumentation	Apply appropriate sensors, instrumentation, and/ or software tools to make measurements of physical quantities
Models	Identify the strengths and limitations of theoretical models as predictors of real-world behaviours. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles
Experiment	Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterize an engineering material, component, or system
Data Analysis	Demonstrate the ability to collect, analyse, and interpret data, and to form and support conclusions. Make order of magnitude judgments and use measurement unit systems and conversions.
Design	Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from

	requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements.
Learn from Failure	Identify unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions.
Creativity	Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving.
Psychomotor	Demonstrate competence in selection, modification, and operation of appropriate engineering tools and resources.
Safety	Identify health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly.
Communication	Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.
Teamwork	Work effectively in teams, including structure individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable
Ethics in the Laboratory	Behave with highest ethical standards, including reporting information objectively and interacting with integrity.
Sensory Awareness	Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems.

Radin Salim et al. (2013) built on Feisel and Rosa's classification to develop a survey instrument called 'Measuring the Learning Outcomes of Laboratory Work' (MeLOLW). They group the learning objectives into cognitive, psychomotor, and affective learning domains and define a total of 23 laboratory work learning outcomes. The tool was tested with a small group of students to assess their perception of the learning outcomes of laboratory work.

More recently Post et al. (2019) undertook a review of the learning benefits of remote labs. They reviewed previous studies in terms of their assessment of cognitive, behavioural and affective learning outcomes. Based on a review of 23 papers, they observed that to date the evaluation of learning benefits of remote labs has been superficial. But based on the information available, cognitive outcomes were mainly measured by tests, behavioural outcomes were measure through usage data and affective outcomes from student evaluations.

Previous scholarship research at the Open University has collated publications that report on OpenSTEM Labs activities. Berry (2019a) reviewed previous evaluation studies of remote and virtual laboratories and her findings have some similarities with Post et al (2019), concluding that the majority (87%) or previous studies were descriptive in nature with only 9% being evaluative. Richardson (2019) performed an extensive review of online practical science at the Open University for biology, health sciences, biochemistry and geoscience. Richardson's review collates previous studies covering a wide range of studies including student perspectives, accessibility and social learning. Brodeur et al. (2015) undertook an extensive study on authenticity, social learning and multifunctionality in OpenSTEM Labs activities, using surveys, focus groups and semi-structured interviews to elicit student opinions on 26 unique experiments.

The literature review has identified a number of approaches to assess the learning objectives of online laboratories, however there is no agreed approach. Much of the previous work has been specifically developed for Engineering courses and does not provide full coverage of the learning objectives in other STEM subjects.

3.2 Developing an OpenSTEM Labs experiment classification scheme.

The aim of this project is to investigate the breadth of learning objectives and skills developed in OpenSTEM Labs experiments and it is proposed to do this by developing a classification scheme for OpenSTEM Labs activities. The literature review has identified a range of existing classification schemes, but there is no agreed approach to classifying activities or learning outcomes and the terminology used between authors is not always consistent. Building on existing approaches in the literature, a two-part classification scheme for OpenSTEM Labs activities has been developed – firstly a classification scheme for experiment and interaction types and secondly a classification scheme for learning objectives. These are described in the following section.

3.2.1 Classification of online experiment types

Previous research has classified types of online laboratories in different ways, however, none of the existing classification schemes meet our needs. The classification scheme proposed by Zutin et al. (2005) scheme provides a useful high-level model of laboratory types but is not sufficiently detailed to capture the full range of activity types and interaction types. We have therefore extended the Zutin model to further allow for more detailed classification, incorporating additional attributes from the literature. The original Zutin and our extended online laboratory classification schemes are shown in Figure 3.

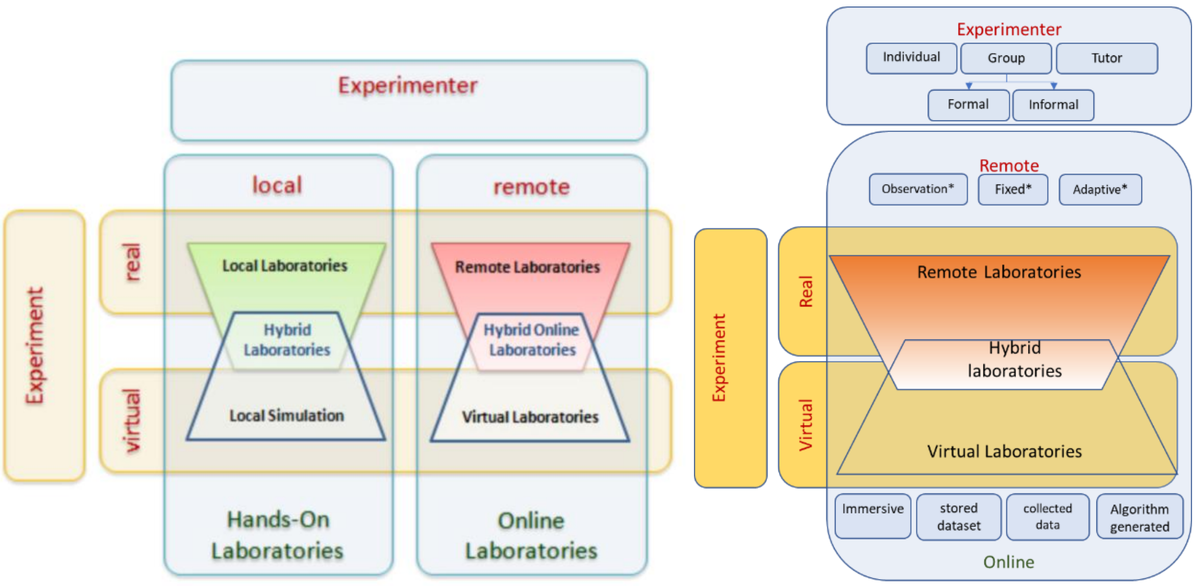


Figure 3 (a) Classification of Laboratories from Zutin et al. (2010) and (b) extended classification scheme for online laboratories building on Zutin et al.

We have also identified a number of other attributes from the literature that provide a richer description of the student interaction with online laboratories as shown in Figure 4. This classification scheme provides a detailed representation of the activity type and student interactions. A glossary of the definitions for each attribute is provided in Appendix 1.

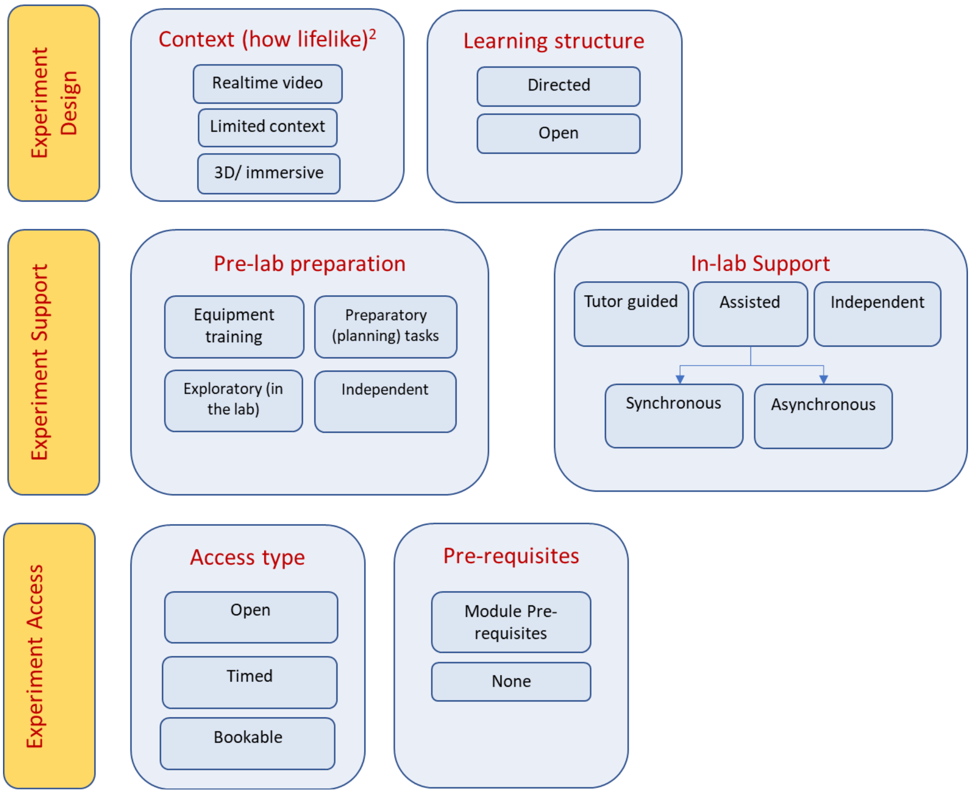


Figure 4 Additional attributes for classification scheme of online laboratories

3.2.2 Classification of online laboratory learning objectives

A useful starting point for classifying student learning is Biggs and Tang's constructive alignment model that defines curriculum design in terms of a small number of intended learning outcomes that must be achieved by students (Biggs and Tang, 2011). A curriculum is then designed to deliver teaching and learning activities that address the intended learning outcomes – hence there is a mapping between activities and learning outcomes. Practical laboratories are a means to deliver teaching and learning activities that address lower-level learning objectives that build towards the high-level learning outcomes.

As discussed in the literature review, much of the previous research into classification schemes for learning outcomes and/ or objectives for online laboratories has been to support accreditation of undergraduate engineering courses. Accredited engineering degrees in the UK must meet learning outcomes defined by the Engineering Council Accreditation of Higher Education Programmes

(AHEP) framework (Engineering Council, 2014). AHEP requires that graduates achieve learning outcomes in six key areas of learning - science and mathematics, engineering analysis, design, economic, legal, social, ethical and environmental context, engineering practice and additional general skills. The learning outcomes in engineering practice include understanding of relevant materials, tools and equipment and a practical knowledge of workshop and laboratory practice (Engineering Council, 2014). In the United States the equivalent accreditation scheme is referred to as ABET (Accreditation Board for Engineering and Technology) and this also provides defined technical outcomes that a student must meet. Several researchers have used the ABET technical outcomes as the basis for classifying learning outcomes.

Initial trial classifications of several OpenSTEM Labs activities were undertaken by members of the project team using both the Brinson and Feisel and Rosa classification schemes. It was found that the action-oriented objectives used by Feisel and Rosa provided more useful information about the activities than the higher-level Brinson learning outcomes. However, the Feisel and Rosa classification was designed for an engineering context, so there were some difficulties applying the scheme to science activities. For example, the Feisel and Rosa classification does not include the inquiry and analytical skills that are identified by Brinson as being important for natural sciences and does not refer directly to underpinning subject knowledge and understanding.

A revised OpenSTEM Labs activity learning objectives classification scheme has therefore been developed building on the Feisel and Rosa scheme, with additional categories for knowledge and understanding, and inquiry based on Brinson's definitions. The descriptors for each learning objective have also been adjusted to be more inclusive to science subjects. The classification scheme is presented in Table 6.

Table 6. Classification scheme for OpenSTEM Labs activity learning objectives (developed from Feisel and Rosa (2005) and Brinson (2015))

Short descriptor	**Long descriptor**
Develop subject knowledge and understanding	Develop subject knowledge by confirming, applying, visualizing, and/or solving problems related to module content.
Apply appropriate instrumentation to make measurements	Apply appropriate sensors, instrumentation, and/ or software tools to make measurements
Use theoretical models to predict behaviour	Identify the strengths and limitations of theoretical models as predictors of real-world behaviours. This may include evaluating whether a theory adequately describes an event and establishing or validating a relationship between measured data and underlying principles

Devise an experimental approach	Devise an experimental approach, specify appropriate equipment and procedures, and implement them.
Collect data	Demonstrate the ability to collect data and make observations
Analyse and interpret data	Demonstrate the ability to~~,~~ analyse, and interpret data, create and test hypotheses and to form and support conclusions
Identify unsuccessful outcomes and learn from failure	Identify unsuccessful outcomes due to limitations in experimental design or faulty equipment, code, design, and then develop effective solutions.
Demonstrate creativity in problem solving	Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving.
Demonstrate competence in operating apparatus	Demonstrate competence in selection, modification, and operation of appropriate scientific/ engineering apparatus and resources.
Identify and deal with health and safety issues	Identify health, safety, and environmental issues related to laboratory work, and deal with them responsibly.
Communicate effectively about laboratory work	Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.
Work effectively in teams	Work effectively in teams, including structure individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable
Behave with high ethical standards	Behave with highest ethical standards, including reporting information objectively and interacting with integrity.
Use human senses to gather information	Use the human senses to gather information and to make sound scientific/ engineering judgments in formulating conclusions about real-world problems.
Design, build, or assemble a product	Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging

	a prototype, system, or process using appropriate tools to satisfy requirements.

3.3 OpenSTEM Labs activity mapping process

An mapping process has been defined to provide a structured approach to using the classification scheme presented in Section 3.2. The aim of the process is to clearly define the steps that should be followed to map an activity and record the data in a consistent way.

The mapping processes was developed iteratively through the project. Initial mapping trials were undertaken by two team members who each mapped the same two activities independently and compared results during an online meeting. An agreed mapping was recorded for each activity. Some definitions in the classification scheme were adjusted after this trial and the mapping process was documented. After these initial trials it was decided that an information template should be created to ensure that a consistent set of information is collected for each activity. Finally, the mapping process was trialled by a new project team member who had not been involved in the development of process and he provided feedback. Figure 5 provides an overview of the final mapping process and the steps are described in more detail in Appendix 2.

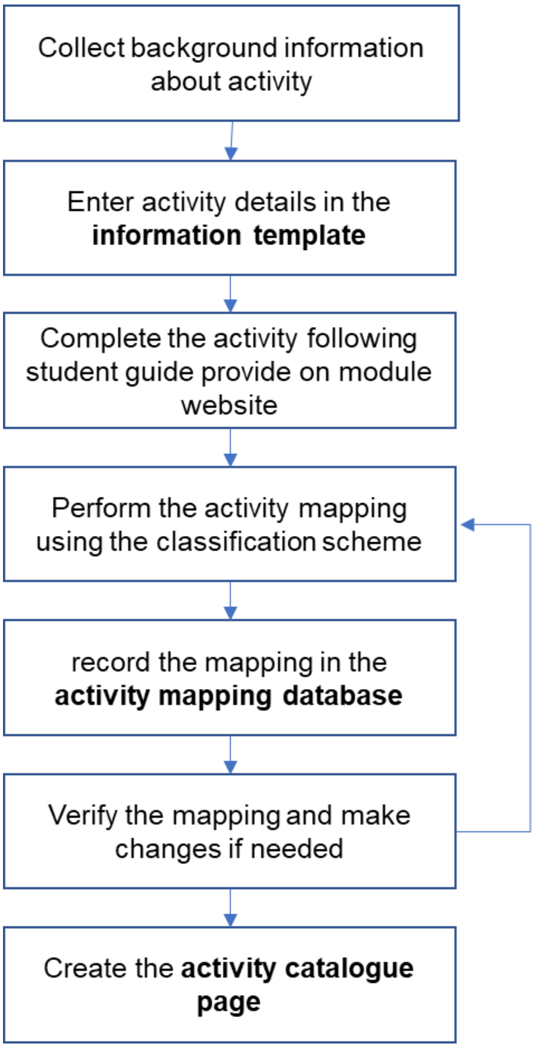


Figure 5 Flow chart for activity mapping process.

The documents to be completed in the mapping process are as follows (example documents are provided in Appendix 3):

1. **Information template** – records details of the activity, including web links to the relevant information on the module and the OpenSTEM Labs websites, assessment details, learning outcomes and a summary of the main steps in the activity
2. **Activity mapping database** – used to record details of all mapped activities in a searchable form. The spreadsheet template uses drop down menus for data entry to ensure consistency and includes notes with reminders of the definitions for each time and each activity is stored as a single column in the database
3. **Activity catalogue page** – key findings from the activity mapping are stored in a visual template. Template pages can be collated together to provide a catalogue of OpenSTEM Labs activities highlighting the key features of each activity.

4 Findings

Twenty-three OpenSTEM Labs activities were mapped using the classification scheme from a total of 79 currently used on modules in the Faculty. The mapped activities cover a range of subjects including biology, health, physics and engineering. Activities have been mapped from three modules that make extensive use of the OpenSTEM Labs (SDK100, SXPS288 and T212) plus a small number of other activities from other modules (SXHL288, SK299, T271, T272, S112).

The activity mapping was undertaken by three project team members. Where possible the team member mapping the activity had direct teaching experience of the activity being mapped and where this was not possible, the results were verified by another team member or an Associate Lecturer with experience of the activity. All the activity mappings were collated in the activity mapping database in an Excel spreadsheet. The data was organised to allow for automatic filtering to allow for easy data analysis.

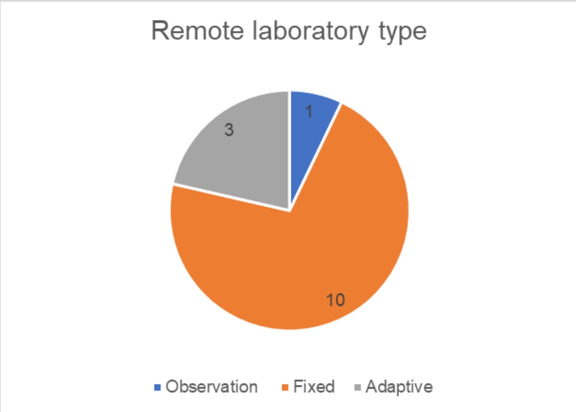
A summary of the 23 mapped activities is provided in Table 7. These activities represent approximately 30% of the total activities in the OpenSTEM Labs. Twelve of the mapped activities were remote and nine were virtual.

Table 7. Breakdown of mapped activities.

Discipline	**Total number of activities**	**Number of Remote activities**	**Number of Virtual activities**
Health/ Biology	7	0	7
Engineering/ Electronics	10	8	0
Earth sciences	1	0	1
Astronomy/ Physics	5	4	1
Total	23	12	9

It can be seen from the data in Table 7 that there is a difference in approach between different disciplines with all the engineering activities being remote experiments and all the biology activities being virtual. It is not entirely clear whether this is difference is intrinsic to the subject areas or due to the choice of activities to map of custom and practice in the schools. Hossain et al. (2015) highlight that for geological sciences “a major challenge compared to other online platforms (such as remote operation of physics experiments) is the maintenance effort of the biological material, i.e., to keep it stable and responsive” which may be a reason why health/ biology activities are more likely to be virtual. Brinson (2105) highlights the importance of practical skills for Engineering and the need to develop practical skills in order to meet accreditation requirements and this may have influenced the decision to focus on remote experiments in Engineering.

Figure 6 shows the interaction types used in the experiments. For the remote experiments, 1 activity was an observation experiment, 10 used a fixed environment and 3 provided an adaptive environment, where the experiment environment was remotely changeable. It is notable that the physics experiments were more likely to be adaptive, for example with astronomy students choosing their own observing targets and needing to react to weather conditions. The physics activities were also generally longer in duration than the engineering activities. For the virtual activities, the most common interaction type was stored dataset (5), followed by algorithm generated (2), collected data (1) and immersive (1). There is an emphasis on using real data for activities for biological sciences, with collected data more commonly being used in human activities. In the majority of the activities, students worked individually (15), with 7 activities involving group work (2 organised students into formal groups, and 5 in informal groups).



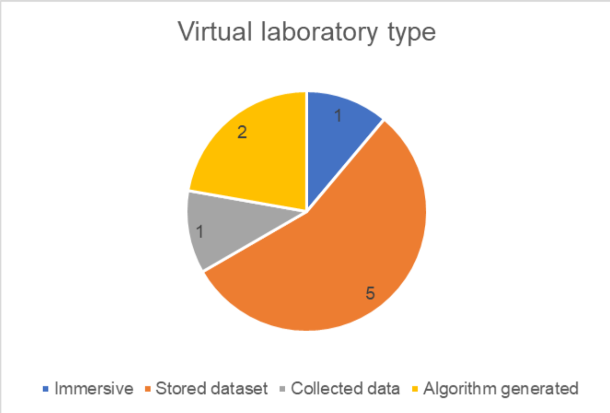


Figure 6. Breakdown of remote and virtual laboratories by type (based on 23 mapped activities)

The number of activities that addressed each learning objective at least "to some extent", subdivided by activity type are shown in Figure 7. As might be expected, all the activities develop subject knowledge and understanding and most (n = 21) analyse and interpret data at least to some extent. The other most common learning objectives addressed are data collection, apply appropriate instrumentation to make measurements, demonstrate competence in operating apparatus and using the human senses to gather information. It is notable that relatively few activities address the learning objectives related to health and safety issues and behaving with high ethical standards. Both of these objectives are important for accreditation standards, however, they may be addressed elsewhere in the curriculum and not in online laboratories.   Lynch and Ghergulescu (2017) state that online laboratories may not be very beneficial for learning about health and safety. Some learning objectives that are addressed by only a few activities are only relevant to a limited range of subject areas – for example "design, build or assemble a product" (n = 4) is only applicable to engineering.

There are also some differences observed between the patterns of learning objectives for remote and virtual activities. As might be expected, remote experiments have more focus on demonstrating competence in operating apparatus, applying instrumentation to make measurements and using theoretical models to predict behaviour. Virtual activities have a greater emphasis on data collection, analysing and interpreting data and communicating about laboratory work.

Seven activities have the learning objective “to work effectively in teams”. Teamwork is a requirement for professional accreditation in some subject areas and hence an important learning objective for online practical work. However, previous research has reported group work being a negative experience by students studying online/distance practical science (Nicholas, 2016) and Brodeur et al. (2015) reported that many students chose online practical science courses as they wish to opt out of collaborative learning and social interactions. More research would be required to determine the effectiveness of teamwork activities in online laboratories.

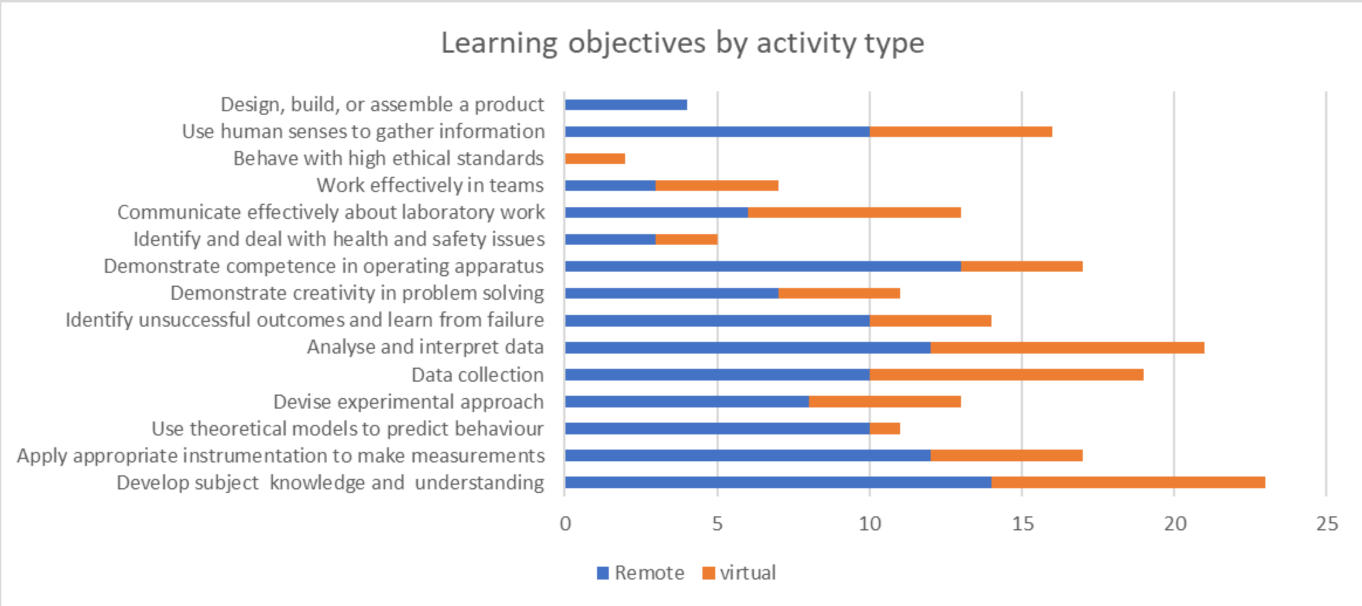


Figure 7 Number of activities that addressed each learning objective at least “to some extent”, subdivided by activity type (based on 23 mapped activities)

5 Impact

This eSTEeM project has investigated the learning objectives and skills developed in OpenSTEM Labs activities. A literature review was performed that has allowed us to understand the wider landscape of online laboratories and will provide a useful resource for future researchers in the first. A glossary of terms has also been created to provide a standard set of definitions based on the literature.

Building on previous work in the literature, a classification scheme for OpenSTEM Labs activities was developed. This classification scheme provides a consistent way to capture details of activities and a structured process has been developed for data collection that allows people to map activities following a consistent approach.

Twenty-three OpenSTEM Labs activities have been mapped using the classification scheme. The majority of the mapped activities are from three modules that make extensive use of the OpenSTEM Labs (SDK100, SXPS288 and T212) and the remainder are from other biology and engineering modules (SXHL288, SK299, T271, T272, S112).

One of the key outcomes of the project is a better understanding of the range of interaction types and learning objectives that are developed in OpenSTEM Labs activities. The database of activities and the associated documentation will be a valuable resource for module teams and others who are interested in using or developing new activities. For example, the database will allow people to search for activities by learning objective or type, making it easier to find and reuse existing activities. Further work will be required to map all OpenSTEM Labs activities, and it is proposed that the mapping process could be incorporated into the development process for new activities. This would allow us to build up the database over time. A set of catalogue pages have also been create to provide a one page summary of each activity.

A secondary benefit of the classification scheme is for module teams planning OpenSTEM Labs activities. The list of learning objectives can be used as a starting point for activity design, helping team members to consider the types of interaction/ activities a student could undertake in the activity. Once the key learning objectives have been identified, the database can be searched to identify existing activities that develop that learning objective. It is proposed that this process be embedded into the early planning stages of future OpenSTEM Labs activities.

The project has also raised some questions about how students learn in online labs. There is a tension between structuring labs to make them self-explanatory so that they can be completed by students independently and removing the aspects of uncertainty that are inherent in experimental work. Care needs to be taken to ensure that activities are designed to achieve the desired learning objectives, and that key learning aspects such as health and safety are not to “designed-out” of activities. This is in alignment with Brodeur et al (2015) who report that online science students place high value on having 'messy' data from which they can make genuine mistakes rather than data that was computers generated or modelled. Future research could be undertaken to elicit feedback from students about their experiences in the labs and possibly compare student engagement with module outcomes.

6 List of deliverables

Title	Filename
eSTEeM project final report	OpenSTEM Labs eSTEeM project Final Report – in template.pdf
Database of OpenSTEM Labs activities (selected activities in Biology/ Health, Engineering and Physics)	Database of selected OpenSTEM Labs activities.xlsx
Activity Classification and Learning Objectives Catalogue (selected activities in Biology/ Health, Engineering and Physics)	Collated OpenSTEM Labs catalogue pages.pdf

7 Figures and tables

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8 References

Berry, E. (2019a) Remote and virtual laboratories - Evaluation studies

Berry, E. (2019b) Remote and virtual laboratories – the OU contribution

Biggs and Tang (2011) Teaching for Quality Learning at University (Fourth Edition). Open University Press, McGraw-Hill Education

Brinson, J. R. (2015a). Learning outcome achievement in non-traditional (virtual and remote) Mead, P. F., & Bennett, M. M. (2009). Practical framework for Bloom’s based teaching and assessment of engineering outcomes. Eleventh International Topical Meeting on Education & Training in Optics and Photonics St. Asaph, North Wales, United Kingdom, 5-7 June 2009. https://doi.org/10.1117/12.2208044

Brinson, J.R. (2015b) Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research. Computers and Education, 87, 218–237. https://doi.org/10.1016/j.compedu.2015.07.003

Brodeur M, Minocha S, Kolb U & Braithwaite N (2015). Designing online laboratories for optimal effectiveness: undergraduate priorities for authenticity, sociability and metafunctionality. In: 15th International Conference on Technology, Policy and Innovation, 17-19 June 2015, The Open University, Milton Keynes.

de Jong T, Linn MC, Zacharia ZC. Physical and virtual laboratories in science and engineering education. Science. 2013 Apr 19;340(6130):305-308.

Feisel, L. D. and Rosa, A. J. (2005) 'The Role of the Laboratory in Undergraduate Engineering Education', Journal of Engineering Education, 94(1), pp. 121–130. doi: 10.1002/j.2168-9830.2005.tb00833.x.

Hatherly, P. A., Jordan, S. E., & Cayless, A. (2009). Interactive screen experiments - Innovative virtual laboratories for distance learners. European Journal of Physics, 30(4), 751–762. https://doi.org/10.1088/0143-0807/30/4/008

Hossain, Z., Jin, X., Bumbacher, E.W., Chung, A.M., Koo, S., Shapiro, J.D., Truong, C.Y., Choi, S., Orloff, N.D., Blikstein, P. and Riedel-Kruse, I.H., 2015, April. Interactive cloud experimentation for biology: An online education case study. In Proceedings of the 33rd annual ACM conference on human factors in computing systems (pp. 3681-3690). ACM.

Kennepohl, D (2010) 'Remote Control Teaching Laboratories and Practicals' . pp. 167-182. In: Kennepohl, D. and Shaw, L. eds. Accessible Elements : Teaching Science Online and at a Distance. Edmonton: Athabasca University Press.

Lynch, T. and Ghergulescu, I., (2017). Review of virtual labs as the emerging technologies for teaching STEM subjects. In INTED2017 Proc. 11th Int. Technol. Educ. Dev. Conf. 6-8 March Valencia Spain (pp. 6082-6091).

Ma, J., & Nickerson, J. V. (2006). Hands-on, simulated, and remote laboratories: A comparative literature review. ACM Computing Surveys, 38(3), 1. https://doi.org/10.1145/1132960.1132961

Nicholas, V. (2016) Gathering student perception about online/distance practical science at level 1. eSTEeM Final Report. Available at: https://www.open.ac.uk/about/teaching-and-learning/esteem/sites/www.open.ac.uk.about.teaching-and-learning.esteem/files/files/ecms/web-content/2016-02-Vic-Nicholas-Final-Report-phase-1.pdf

Open University (2021) *The OpenSTEM Labs* Available at https://stem.open.ac.uk/study/openstem-labs (Accessed June 7, 2021)

Orduna, P., Rodriguez-Gil, L., Garcia-Zubia, J., Dziabenko, O., Angulo, I., Hernandez, U., & Azcuenaga, E. (2016). Classifying online laboratories: Reality, simulation, user perception and potential overlaps. Proceedings of 2016 13th International Conference on Remote Engineering and Virtual Instrumentation, REV 2016, February, 224–230. https://doi.org/10.1109/REV.2016.7444469

Post, L. S., Guo, P., Saab, N., & Admiraal, W. (2019). Effects of remote labs on cognitive, behavioral, and affective learning outcomes in higher education. Computers and Education, 140(December 2018). https://doi.org/10.1016/j.compedu.2019.103596

Radin Salim, K. R., Rosmah, A. L. I., Hussain, N. H., & Haron, H. N. (2013). An Instrument for Measuring the Learning Outcomes of Laboratory Work. Proceedings of the IETEC'13 Conference, Ho Chi Minh City, Vietnam, 901(November), 1–15.

Richardson, C. (2019). A review of online practical science- Biology Health Sciences, Biochemistry and Geoscience. eSTEeM project report.

Rivera, L. F. Z., & Petrie, M. M. L. (2016). Models of collaborative remote laboratories and integration with learning environments. International Journal of Online Engineering, 12(9), 14–21. https://doi.org/10.3991/ijoe.v12i09.6129

Sharples M, Adams A, Alozie N, Ferguson R, Fitzgerald E, Gaved M, McAndrew P, Means B, Remold J, Rientes B, Roschelle J, Vogt K, Whitelock D & Yarnall L (2015). Innovating Pedagogy 2015: Open University Innovation Report 4. Milton Keynes: The Open University

Trevelyan, J. (2004, June 27). Lessons learned from 10 years experience with remote laboratories. Paper presented at the International Conference on Engineering Education and Research in Olomouc, Czech Republic. Retrieved February 11, 2007 from http://telerobot.mech.uwa.edu.au/Information/Trevelyan-INEER-2004.pdf

Waldrop, M. M. (2013) 'The virtual lab: confronted with the explosive popularity of online learning, researchers are seeking new ways to teach the practical skills of science.', Nature. Nature Publishing Group, 499(7458).

Zutin DG, Auer ME, Maier C, and Niederstatter M, "Lab2go – A repository to locate educational online laboratories," in Proc. of IEEE EDUCON 2010 Conference: The Future of Global Learning Engineering Education, Madrid, Spain, 14-16 April 2010, IEEE, pp. 1741-1746

Appendices

Appendix 1 Glossary of online laboratory types

Term	Sub-term	Definition
Online laboratory		interactive experiments provided over the internet – can be virtual or real.
Remote laboratory		A real physical laboratory that is capable of being accessed through a network. (Rivera and Petrie, 2016)
Remote experiment		A real device designed to conduct experiments over the internet. When launched, relevant data is collected and displayed to the users via a web browser. This interface may enable input parameters to be defined (Rabek and Zakova, 2020, p1)
Remote experiment	Observation	The experiment parameters as well as the experiment environment are fixed. This kind of experiments allows users only the observation of an experiment. (Zutin, 2010, pp1743)
Remote experiment	Fixed	The experiment environment is fixed but the experiment parameters are remotely tunable. Furthermore, it is possible to control one or more measurement instruments also remotely. (Zutin, 2010, pp1743)
Remote experiment	Adaptive	The experiment parameters as well as the experiment environment are remotely changeable. This definition includes for example the modification of a circuit. (Zutin, 2010, pp1743)
Virtual Laboratory		A virtual laboratory does not use real physical equipment, but simulates the experiment by replicating the behaviour of physical equipment. Controls can be included for users to manipulate the simulated experiment. Real data or data generated by algorithm may be used as part of the simulation.
Virtual experiment		Imitations of real experiments [where] all the infrastructure required for laboratories is not real, but simulated on computers. (Ma and Nickerson, 2006)
Virtual experiment	Immersive	Students interact with an online experiment that uses a virtual world to simulate an experiment or environment on a computer
Virtual experiment	Stored Dataset	Students interact with an online experiment that uses a dataset that has been collected from real experimental data and stored in the activity
Virtual experiment	Collected Data	Students interact with an online experiment that uses data collected by the students themselves as part of the activity

Virtual experiment	Algorithm Generated	Students interact with an online experiment that uses data that has been generated using a computer algorithm of software
Hybrid laboratories		Remote access to real laboratory and virtual laboratory (Adapted from Rivera and Petrie, 2006, p15)
Experimenter	Individual	Students undertake experiment individually
Experimenter	Group	Students undertake experiment as part of a formal or informal group
Experimenter	Tutor	Experiment is conducted by a tutor or demonstrator while students observe remotely

Additional Terms for OpenSTEM Labs

Term	**Sub-term**	**Definition**
Experiment Design		
Context (how life like)		The context for an experiment is the way in which it presents the task and equipment. The closer to 'real life' the richer the context. Context can vary from basic to 'life-like'. If students are able to understand a model at a deep level (particularly the relationship it has to reality) then their ability to use that model to reason about aspects of reality is enhanced." Matchet, Lowe and Gutl (2012, p527)
Context (how life like)	Realtime video	Students control and/ or monitor experiment via real-time video looking at the physical equipment or experiment output
Context (how life like)	Limited context	Visual context of experiment is limited
Context (how life like)	3D/ Immersive	Virtual worlds are one way of providing a context which is close to real-life and are sometimes referred to as immersive or 3D context. Students interact with a virtual world using their computer. Interaction may be through a 2D display or 3D immersive technology.
Learning Structure		
Learning Structure	Directed	Students are guided through experiment following a defined process
Learning Structure	Open	Students are able to explore the experiment freely without following a set process
Experiment Support		
Pre-lab preparation		Guidance for remote laboratory work will vary depending on how the module team wish students to be prepared. This can range from detailed preparation through any of text, audio/video

		material, tutorials, experience of previous remote experiments to less formal preparation so that students use trial and error for exploratory learning
Pre-lab preparation	Equipment training	Students receive training before starting the experiment
Pre-lab preparation	Preparatory (planning) tasks	Students undertake preparatory work outside the laboratory
Pre-lab preparation	Exploratory (in the lab)	Students engage in simplified activities in the laboratory before undertaking the experiment
Pre-lab preparation	Independent	No prerequisites for experiment
In-Lab support		Support within the remote laboratory can take many forms. For example, in an online tutorial with a tutor present, via audio or text chat or via online forums.
In-Lab support	Tutor guided	Tutor is online with students and guides them through the experiment in real time
In-Lab support	Assisted: synchronous/asynchronous	Students can ask for support using live chat/ audio (synchronous) or on VLE forums (asynchronous)
In-Lab support	Independent	There is not support for the experiment
Experiment Access		
Access type		
Access type	Open	Students can access the experiment at any time an as frequently as they wish
Access type	Timed	The experiment takes place at a fixed time and students must engage with it at that time
Access type	Bookable	Students are allocated a time, or can book a time in which to undertake their experiment. May be able to book several slots, or number of opportunity to do the experiment may be limited. Time experiment is available may also be constrained
Pre-requisites		Tasks, activities or assessment may need to be completed before student able to access the experiment. There may be threshold requirements for this access.
Pre-requisites	Module-prerequisites	Student must have completed pre-requisite activities in module before starting the experiment. These may relate to underlying theory or use of equipment
Pre-requisites	none	The experiment has no pre-requisites

Appendix 2 Open STEM Labs mapping process

OpenSTEM Labs mapping process (existing activities)

1. Collect background information about the activity and record in the template *Information template for OpenSTEM Labs activity mapping.docx*
   i. Visit the relevant module website and find where the activity occurs in the module. Check what information is provided to students. *Add all relevant module website links to the information template*
   ii. Check for assessments that are linked to the activity. *Add relevant assessment links to the information template*
   iii. Search the module website for learning outcomes that are relevant to the activity. *Add relevant learning outcomes links to the information template*
   iv. Request access to the OpenSTEM Labs activity and the relevant module website(s) by emailing openstemlabs@open.ac.uk
   v. Visit the OpenSTEM Labs website for the activity at https://learn5.open.ac.uk/course/view.php?id=2 and read the activity description. *Add the activity link to the information template*
   vi. If possible complete the activity following the student instructions, or if not possible, familiarise yourself with the instructions. *Write a short summary activity aim and the main activity steps in the information template*
2. Map the activity
   a. Create a new column for the activity in the OpenSTEM Labs activity database Excel spreadsheet
   b. Map the activity against the classifications in the database using the information you collected in Step 1. Use the glossary in Appendix A to check the definitions of each category if required
   c. Map the learning objectives for the activity against the categories in the database using the information you collected in Step1. For each item determine whether the learning objective is addressed, partially addressed, or not addressed at all. Use the long descriptors of the learning objectives in Table 1 to help you to interpret the meaning learning objectives.
3. Verify the mapping
   a. Ideally the mapping of each activity should be undertaken independently by two people and checked for consistency afterwards. At least one person doing the mapping should have prior knowledge of the activity/ module (for example an AL teaching the module or member of the module team)
   b. Completed mappings should also be verified by a member of the module team if possible.
4. Create the documentation
   a. Ensure that the information template is complete
   b. Ensure that you have recorded answers for all categories in the Excel spreadsheet
   c. Create a catalogue page for the activity using the catalogue pages template

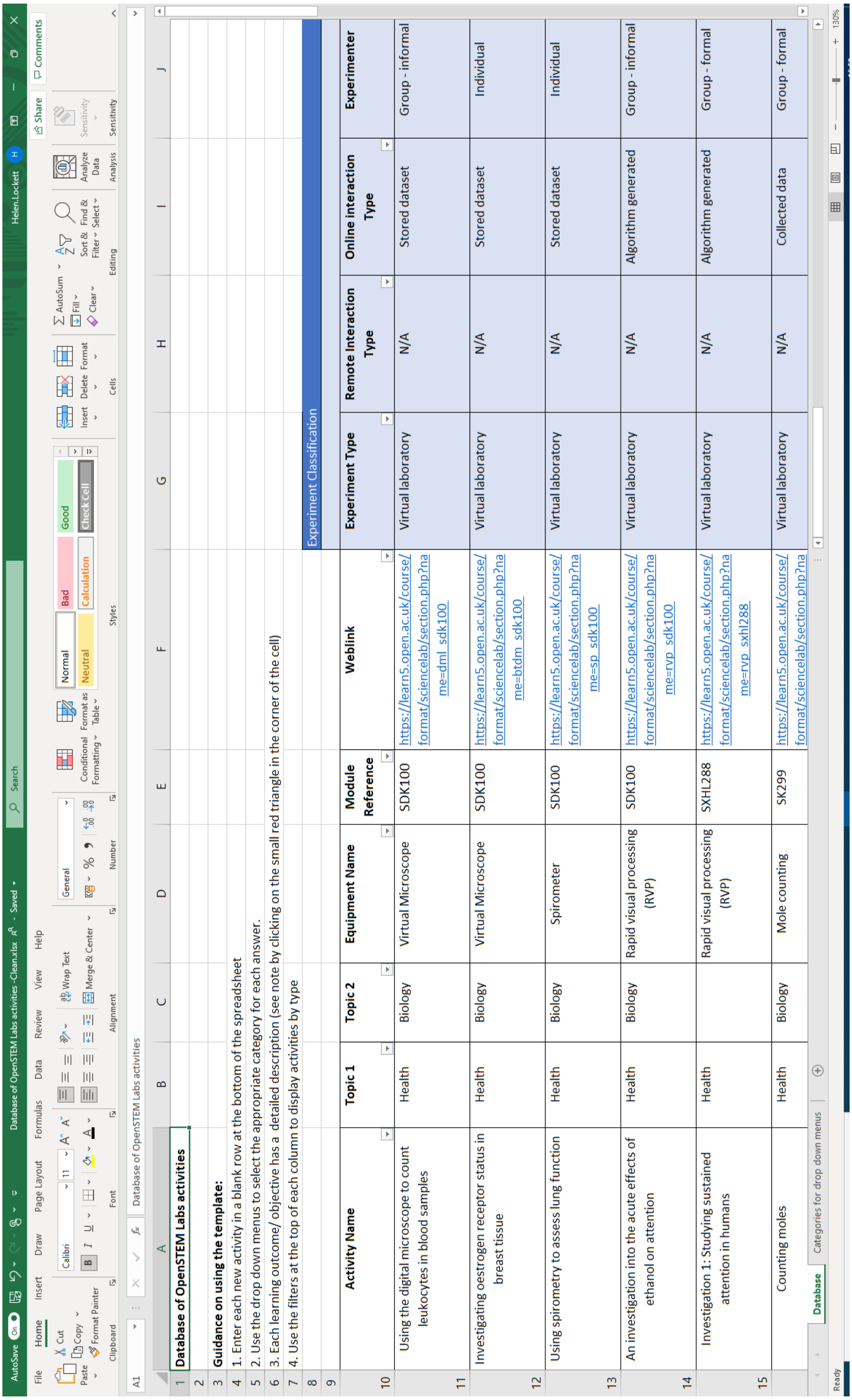
Appendix 3 Mapping process documents

1. Information template

Information Collection template for OpenSTEM Labs activity mapping

Activity title:	
Link to activity web site	
Links to relevant module website pages	
Links to activity/ module learning outcomes	
Links to related assessments	
Short summary of activity aims and the main activity steps	

2. Database of OpenSTEM Labs activities (Excel Spreasheet)



Database of OpenSTEM Labs activities

Guidance on using the template:

1. Enter each new activity in a blank row at the bottom of the spreadsheet
2. Use the drop down menus to select the appropriate category for each answer.
3. Each learning outcome/ objective has a detailed description (see note by clicking on the small red triangle in the corner of the cell)
4. Use the filters at the top of each column to display activities by type

						Experiment Classification			
Activity Name	**Topic 1**	**Topic 2**	**Equipment Name**	**Module Reference**	**Weblink**	**Experiment Type**	**Remote Interaction Type**	**Online interaction Type**	**Experimenter**
Using the digital microscope to count leukocytes in blood samples	Health	Biology	Virtual Microscope	SDK100	https://learn5.open.ac.uk/course/format/sciencelab/section.php?name=dml_sdk100	Virtual laboratory	N/A	Stored dataset	Group - informal
Investigating oestrogen receptor status in breast tissue	Health	Biology	Virtual Microscope	SDK100	https://learn5.open.ac.uk/course/format/sciencelab/section.php?name=btdm_sdk100	Virtual laboratory	N/A	Stored dataset	Individual
Using spirometry to assess lung function	Health	Biology	Spirometer	SDK100	https://learn5.open.ac.uk/course/format/sciencelab/section.php?name=sp_sdk100	Virtual laboratory	N/A	Stored dataset	Individual
An investigation into the acute effects of ethanol on attention	Health	Biology	Rapid visual processing (RVP)	SDK100	https://learn5.open.ac.uk/course/format/sciencelab/section.php?name=rvp_sdk100	Virtual laboratory	N/A	Algorithm generated	Group - informal
Investigation 1: Studying sustained attention in humans	Health		Rapid visual processing (RVP)	SXHL288	https://learn5.open.ac.uk/course/format/sciencelab/section.php?name=rvp_sxhl288	Virtual laboratory	N/A	Algorithm generated	Group - formal
Counting moles	Health	Biology	Mole counting	SK299	https://learn5.open.ac.uk/course/format/sciencelab/section.php?na	Virtual laboratory	N/A	Collected data	Group - formal

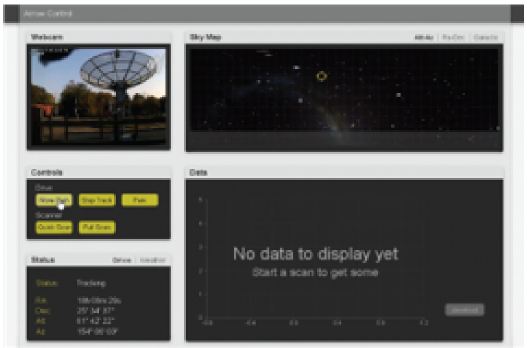
3. Activity Catalogue Page Template

The OpenSTEM Labs

Title: ARROW

Experiment Details:

Equipment Name: **Remote Telescope**
Module Reference: **SXPS288**



Experiment Classification:

Experiment Type: **Remote laboratory**
Remote Interaction Type: **Adaptive**
Experimenter: **Group- informal**
Context (how life-like): **Real-time video**
Learning structure: **Directed**
Pre-lab preparation: **Preparatory planning tasks**
Pre-requisites: **Module pre-requisites**
Access type: **Bookable**
In-lab support: **Assessed-asynchronous**

Learning Objectives:

By completing this OpenSTEM Labs activity students *will be able to* …

- Develop subject knowledge and understanding
- Apply appropriate instrumentation to make measurements
- Use theoretical models to predict behaviour
- Data Collection
- Analyse and interpret data
- Demonstrate competence in operating apparatus
- Communicate effectively about laboratory work
- Work effectively in teams

By completing this OpenSTEM Labs activity students will *to some extent* be able to …

- Devise an experimental approach
- Identify unsuccessful outcomes and learn from failure