

Chapter 6

Physical Laboratory-Based Practical Activities in School: A Literature Review centred on Students



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6.1 Introduction

For a long time, the physical laboratory was seen as the key tool for science and science education. Scientists relied on the research laboratory to solve research problems or gather evidence to support their theoretical propositions; science teachers relied on (or felt guilty for not being able to use) the school laboratory to teach science to their students. Although preferences may vary with science disciplines and school levels (Sharpe & Abrahams, 2020), some students, especially the younger ones (Abrahams, 2009), are eager to enter the laboratory to experience the thrill of being scientists. Many of them view science as a practical subject with visual or sonic spectacular ‘experiments’. However, when the novelty wears off, students’ enjoyment in the lab seems to decrease (Abrahams, 2009).

Science is taught not only because it is a practical subject but also because it is a theoretical subject of value for students (Millar, 1998; Osborne & Allchin, 2024). In this sense, science education is not just about watching or performing spectacular ‘experiments’. It encompasses learning science, learning about science, and learning how to do science (Hodson, 1988). Each of these dimensions leads to the development of different competencies and has different requirements and dependencies on the laboratory, with some (namely the third) being more dependent on it than others.

A challenge of using the lab for teaching is that there is unseen science behind the spectacular observations. Hands-on or observational approaches may be appealing

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to students, but they are insufficient for them to learn science concepts and theories (Abrahams & Millar, 2008; Kluge, 2014). Appropriate guidance and debate of ideas are required (Howe & Smith, 1998; Kirschner et al., 2006; Solomon, 1999; Osborne & Allchin, 2024). Missing the link between observation and theories (students' and scientists' theories) impairs students from making sense of the data they collect through observation (Solomon, 1999; Abrahams & Millar, 2008). Those data may depend on students' previous experiences (Millar et al., 2002) and constitute an obstacle to learning, which may reduce their enjoyment of learning in the laboratory (Solomon, 1980), especially when this is no longer a novelty for them (Abrahams, 2009).

Some schools may not have lab facilities to allow students to perform 'experiments' in science. Although this may be frustrating for some students, it may not be necessary to reach some learning outcomes. Also, some 'experiments' may not require a lab; they can be performed in a classroom (given that safety conditions are ensured) and or rely on everyday materials (Gericke, 2023; Leite & Dourado, 2013). In addition, not all activities performed in a lab or using lab equipment and materials are, in fact, experiments (Wellington, 1998b), as some may not require hypothesis testing (Howe & Smith, 1998) and control and manipulation of variables (Wellington, 1998b). There is nothing wrong with it, but experimental and non-experimental activities promote the development of different competencies (Gericke et al., 2023). Differentiating those concepts helps to increase the match between the structure of the activity and the objectives to be attained.

The usual lab activities have progressively integrated digital technologies (e.g., sensors, graphic calculators with LaunchPad Boards, microscopes with digital cameras, etc.). Integrating technologies in the lab activities should not mean replacing physical labs. Rather, it means powering physical lab activities in terms of both learning potential and students' motivation (Dyrberg et al., 2017). Considering the educational potential and the evolution of physical school laboratories, it is worth exploring the extent to which laboratory-based science teaching actually makes a difference in students' education and enjoyment. This chapter presents a critical overview of how research on school practical laboratory-based activities, published in Scopus and or Web of Science-indexed journals and focusing on students, evolved and is influenced by school level. It also discusses future directions for lab-based science education and research in the digital era.

6.2 From Practical Work to Laboratory-Based Practical Activities

For the last 45 years, the words practical work and laboratory work have been used alternately in texts, including books (Solomon, 1980; Woolnough & Allsop, 1985; Woolnough, 1991; Wellington, 1998a; Leach & Paulsen, 1999; Psillos & Niedderer, 2002; Abrahams, 2011), related to teaching science in the school lab. All these

books address the same object: laboratory activities as a tool for school science teaching and learning. One of the designations they use (practical work) has a broader scope than the other (laboratory work) and does not indicate the object it focuses on. Hodson (1988) argued that not all practical activities are lab activities. If one assumes that practical activities are a “planned intervention in the material world” (Abrahams, 2011, p.1), one can think of some activities that can take place in the physical science lab and others that do not occur within it (Hodson, 1988); some can be performed outside the classroom or the school, namely in open spaces, science centres, or industrial contexts (Leite & Dourado, 2013) and others can take place in a variety of labs that have flourished with educational technological advancements, including maker labs (Kyle et al. 2018), fabrication labs (Fonda & Canessa, 2016), robotics labs (Chiazzese et al., 2018), virtual reality labs (Ikhsan et al., 2020), and virtual labs (Dyrberg et al., 2017). However, most practical activities performed in those laboratories do not integrate physical laboratory tools. Some laboratories (e.g., virtual labs) may be more useful for enhancing physical lab activities in the pre-lab phase (Dyrberg et al., 2017) than for replacing them.

Although the authors of the reference books and papers mentioned above tried to clarify the meanings of the words they used and distinguish the concepts they encompass (e.g., Abrahams, 2011; Hodson, 1988; Wellington; 1998b), recent studies continue to use lab work and practical work as synonymous, even though, in some countries, preferences can be observed. Practical work is common in the UK and German contexts, and laboratory work is common in the USA (Hofstein, 2017). In other countries (e.g., Australia, Portugal, Spain, Sweden), the two words coexist, with some authors preferring one and others the other.

We might agree with Gericke et al. (2023) that laboratory work or practical laboratory work would be more appropriate than the other designations to name “practical science activities involving students manipulating and/or observing real objects, including empirical data collection within authentic science-teaching situations” (p. 246), which are the object of this chapter. Nevertheless, those designations may suggest that they address a single entity, while (as will be discussed in the next section) lab activities encompass different types of activities with a diversity of aims and structures. Therefore, we would like to argue that ‘laboratory-based practical activities’ or simply ‘laboratory activities’ would be more appropriate to address what students do when they manipulate and or observe real laboratory objects and materials (alone or integrated with digital technologies) or everyday materials, in a lab or a classroom.

In school contexts, experimental work and investigation are often used interchangeably with laboratory work and practical work. Hodson (1988) argued that some laboratory work is not experiments; doing experiments is engaging in closely controlled events (Hodson, 1988), and not all lab activities (e.g., measuring the pH of a solution) require control and manipulation of variables. This requirement underlies some school lab activities, but the use of a step-by-step, ready-to-follow worksheet often hinders it. The use of this kind of worksheet prevents students from engaging in the cognitively demanding and educationally valuable processes of control and manipulation of variables (Osborne, 2015).

Woolnough and Allsop (1985) considered that science practical work comprises investigations, which they conceptualize as problem-solving activities. They argue that carrying out an investigation requires, among others, the mastery of lab skills associated with exercises (e.g., operating a multimeter), which those authors consider another type of lab activity. An investigation is an open activity that starts with a question to be answered (Crawford, 2014); answering it requires designing and implementing a problem-solving strategy, and assessing the solution(s) obtained as well as the strategy used to reach it (if a solution exists). Some problems (e.g., what affects the speed of a chemical reaction) require control and manipulation of variables to be solved; others do not (e.g., what are the development stages that the bean plant goes through from the time the bean is sown until it produces pods with new beans?), and therefore may be considered non-experimental investigations. In recent research, these concepts are not completely clear. Kluge (2014) uses the term experiments to refer to research projects; Kranz et al. (2023) mix the concepts of experiment and investigation, even though they do it in the context of inquiry-based learning.

Following the previous discussion, it can be argued that scientific experiments are investigations, but not all investigations are experiments (Leite & Dourado, 2013), in the sense that not all of them require hypothesis testing through control and manipulation of variables. Problem-solving and investigations can occur in the lab, but not all problems are solved in the lab (or with lab materials), and not all investigations take place in a science lab. Similarly, all science problem-solving activities are investigations, but some of them do not take place in the lab. Then, it is worth differentiating lab-based experiments, lab-based investigations, and lab-based problem-solving activities. Conceptual accuracy is relevant for highlighting what different activities demand from students and allow them to learn, which in turn depends on the degree of openness of the activity (Leite, 2001), and on the existence (or not) and the features of a lab worksheet.

6.3 Matching Laboratory Activities to Learning Objectives

Hodson (1988) argues that lab activities are necessary to learn how to do science, are not enough for learning science, and are inappropriate for learning about the nature of science. As no theory development path can be replicated in school, having students analyse the historical development of ideas would be more beneficial for learning about science than having them work in school labs (Hodson, 1994). However, the lab may allow students to develop some practical skills (Schwichow et al., 2016) required to understand how science is produced.

As far as learning science is concerned, students need to learn updated science content. To achieve this goal, they do not need to rediscover knowledge discovered by past scientists, and it would not be viable, because, as Millar (1998) points out, what they do in school does not compare to what scientists have done. In addition, lab activities show what happens but do not show why it happens (Woolnough & Allsop, 1985). Making sense of what happens and explaining why it happens requires

creativity, imagination, and insight (Ogborn et al., 1996). This is because there is no direct path between experiments and theory. Rather, there is a complex interplay between them (Leach, 1999), with theory both informing experiments and emerging from them, and being influenced by the observer's previous ideas and expectations (Millar et al., 2002).

Learning how to do science encompasses mastering basic skills (e.g., preparing apparatus, operating equipment and measurement devices, and making a microscopic preparation) and becoming familiar with scientific methodology. Doing school lab activities is appropriate for developing practical skills (Schwichow et al., 2016), but it is not the same as doing science research (Hofstein & Lunetta, 2004); it only enables students to get a flavour of what doing science research is. Thus, this goal may be better reached through internships in research laboratories (Roth et al., 2009) or by engaging students in open-ended investigations (Guillon & Seré, 2002) or research projects (Lewis, 2002).

To analyse the educational potential of laboratory activities, it is useful to think about them as having three steps: before putting into practice the lab procedure (preparation phase), implementation of the lab procedure (dealing with apparatus), and after the implementation of the lab procedure (data analysis, conclusions, and critical reflection and assessment of what was done and achieved). As Osborne (2015) pointed out, “no practical work should be undertaken without a pre- and post-activity” (p. 23). Considering who performs the lab procedure, lab activities can be classified as: lab demonstrations, if the teacher implements the lab procedure and the students observe it actively (with minds-on); or students' lab activities (hands-on, and hopefully, mind-on), if students, individually or in small groups, perform it themselves (Millar et al., 2002) with or without guidance (e.g., a worksheet). Minds-on engaging demonstrations may be enough for students to learn science; hands-on student activities are required for them to develop technical (manipulative) skills; appropriate teacher mediation or guidance is needed for students to develop other competencies relevant to learn how to do science.

A lab activity may contribute to one or more learning outcomes. However, it is worth identifying the main intended learning outcome to design, perform, and assess it accordingly. Then, it is possible to classify lab activities according to the nature of the main learning outcome. Synthesizing and adding to the proposals of some authors, Leite and Dourado (2013) consider exercises, activities for getting a feeling of the phenomena, illustrative activities, activities to uncover what happens if/when..., Preview-Observe-Explain-Reflects (POER) with or without procedure given, and investigations. It is worth emphasizing that school science experiments are a category that arises from another classification criterion. They may intersect some of these categories, namely those related to learning conceptual knowledge and scientific methodology, depending on how open or guided the experiments are.

6.4 Methodology

To attain the research objective, a systematic literature review was conducted. The review followed the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) methodology (Page et al., 2021). PRISMA is useful to guide the reporting of why a systematic review was done, what methods were used, and what results were obtained. According to PRISMA, a process of systematic review should be organized into four phases: identification (searching databases to find records); screening (reviewing titles and abstracts for relevance); eligibility (assessing the full-text articles against inclusion/exclusion criteria); and inclusion (analysing the final set of studies included in the review) to extract data.

For the identification phase, a search of original research articles published in Scopus and or the Web of Science (WoS) databases was conducted. These databases are comprehensive (Pranckutė, 2021) in terms of the journals they include, and complementary (Kumpulainen & Seppänen, 2022) as some journals are indexed by one and not by the other. However, some journals are indexed by both databases (Pranckutė, 2021), and this overlap needs to be addressed in the next stage. Other databases are more comprehensive in indexing non-journal materials (Wilder & Walters, 2021), which are not considered in the type of literature review to be conducted. As the literature review concentrates on empirical research articles only, the two selected databases seem fully appropriate. In addition, they allow the use of convenient filters, which facilitate searching.

Regarding the search criteria, two sets of descriptors (one including words used to address lab activities, and the other including the science disciplines) were combined with the Boolean operator AND. From this combination, papers on non-physical labs, higher education, and non-science research areas were excluded using the Boolean operator NOT. Some additional filters were used, too. They were selected to provide a set of original empirical papers on school students' learning from and opinions on and reactions to physical laboratory activities, published in peer-reviewed journals, and written in English, French, Spanish, and Portuguese (which are the languages mastered by the authors). Research focusing on preschool children was disregarded to limit the revision to school (primary and secondary school). Exclusion of preschool and higher education is due to the large amount of research in the area and limitations of space in the chapter.

The following combinations of keywords, in all fields, were used:

- (“practical work” OR “practical activit*” OR “experimental work” OR “experimental activit*” OR “lab* work” OR “lab* activit*”) AND
- (“science education” OR “science learning” OR “science teaching” OR “chemi* education” OR “Physics education” OR “Biolog* education” OR “Geolog* education” OR “chemi* learning” OR “Physics learning” OR “Biolog* learning” OR “Geolog* learning” OR “chemi* teaching” OR “Physics teaching” OR “Biolog* teaching” OR “Geolog* teaching”) NOT
- (virtual OR “higher education” OR health OR online OR comput* OR engineering OR medic*).

No time limit was established, even though, before 2000, few papers were available online. For that period, papers with full text freely unavailable online were included if the hard versions of the journals were available from the university library only. The searches were done in the month of May, 2025.

The results of the search were 1224 titles for Scopus and 500 titles for the WoS. This led to a total of 1724 papers. As some journals are indexed in both databases, the first search follow-up action consisted of checking the papers' references to eliminate repetitions ($n = 202$). A total of 1522 papers remained for screening. Screening was based on a reading of the title and the abstract. When this was not enough to decide on the eligibility of the article, other parts of the paper (e.g., objectives and methodology) were read and submitted to the inclusion and exclusion criteria. Papers focusing on scientific research ($n = 179$), different disciplines ($n = 30$), other science issues ($n = 461$), higher education ($n = 140$), school textbooks ($n = 23$), pedagogical proposals ($n = 106$), or teachers ($n = 105$), as well as position papers/literature reviews ($n = 107$), and paper with full text unavailable ($n = 228$) were excluded. Ultimately, 143 journal articles were considered consistent with the inclusion criteria and remained for review. The two oldest articles reviewed were published in 1928, in the *Journal of Chemical Education*, and 1981, in *Research in Science Education*. The most recent articles were published in 2025 (two articles, one in *Physical Review Physics Education Research* and the other in *Physics Education*).

Eight questions (presented in the next section) guided the authors in identifying the relevant data to extract from the selected papers. An Excel table was created to record the data and facilitate later analysis. To start, the authors performed a joint analysis of four randomly selected articles to ensure that everyone was following the same rules. Afterwards, one of the authors analysed the first half of the papers, and another author analysed the second half. The three authors discussed some difficult cases to ensure the reliability of the analysis. Decisions were taken by consensus.

Data in the Excel file were used to draw tables containing data relevant to answering the research questions. The articles are grouped into three time periods to enable the uncovering of possible trends in the research. They are also separated by school level to allow some comparison of research carried out in primary and secondary schools. In doing so, this review contributes to the knowledge base, as other recent reviews (e.g., Gericke et al., 2023) do not simultaneously inform about possible changes over time and compare primary and secondary education.

6.5 Findings

This section is organized around the eight research questions that guided data extraction.

Question 1: When and where were the research studies done?

Considering three time periods, the percentages of papers are: 13, 3% before 2000; 39,2% between 2000 and 2012 (limits included), and 47,5% after 2012 (up to the

month of May, 2025). Before 2000, only a small part of papers were available online, which means that the number of papers reviewed is small and below the number of papers published in that period. Despite that, there is a tendency for research to increase over the two more recent periods. Almost half of the papers report research carried out in Europe (46, 1%), mainly the UK and Sweden, followed by Asia (20,3%), especially China and Singapore, America (18,2%), primarily the USA, Oceania (9,1%), mainly Australia, and Africa (6,3%), spread by several countries. Research in Europe, America, and Africa shows a tendency to increase, whereas in Oceania it shows a tendency to decrease. Research in Asia did not change during the two most recent periods, and no paper focusing on Antarctica was reviewed. These results indicate that some continents and countries account for more research than others.

Question 2: What school levels and samples were focused on in the research?

The majority of the studies reviewed (80,4%) concentrated on secondary school (7th–12th grade), 60,1% of which dealt with upper secondary school (grades 10 to 12); 13,2% of the studies reviewed concentrated on primary school (grades 1 to 6), and 6,3% on both levels (in Asia, Europe, and Oceania). Considering the two most recent periods, there is a tendency for research to increase over time in either primary or secondary schools, with a duplication in the former case (5 to 10 studies) and a moderate increase (44 to 56 studies) in the latter case. Studies dealing with both grade levels decreased from 7 to 2. So far, primary school has attracted little attention from researchers, probably because it is not seen as a rich research environment since most primary schools do not have laboratories, or little science is taught at this level.

Concerning samples, 25,9% of the studies include small samples, lower than or equal to 30 students, being 9,1% lower than 10 students; 32,2% use samples between 31 and 120 students (limits included); 9,8% use samples higher than 550; seven studies do not make explicit the dimension of the sample and the others are in the interval 121–550 students. The largest sample ($n = 5194$) was used to study secondary school students' views on several teaching approaches, including practical work. The smallest sample ($n = 2$) was used in a qualitative study, focusing on how students interact when working in a lab. The primary school studies use samples between 11–30 and 261–350 students, and half of them took place within a single school. As for secondary school, 42,6% of the studies took place in a single school, but about one third involved two or more schools, and others took place at the national or international levels; some studies do not provide clear information on where data were collected; large sample studies seem to show a decreasing tendency. These results indicate that most studies were obtained in a specific context with reduced samples, which limits the external validity of the studies.

Question 3: What are the aims of the research studies reviewed, and to what extent did their aims change over time?

About half of the studies (49,6%) focus on the affective dimension (i.e., attitudes, motivation, interest), 35,7% on conceptual learning, and 23,8% on procedural learning (e.g., using measuring instruments, operating equipment, etc.); only 9,8%

focus on epistemological issues, namely on the features of scientific inquiry. Some studies deal with one of these issues, but others deal with two or more issues. There seems to be a slight tendency for studies focusing on the affective or procedural dimensions to be increasing over time, in secondary school; no clear tendency is observed in primary school. The affective dimension is important because it interferes with learning. As there is quite a lot of consensual research on the topic, it may be worth concentrating efforts on other targets, namely in primary school.

Question 4: What science disciplines and themes were focused on in the studies reviewed?

General sciences (33,6%), chemistry (25,9%), physics (16,1%), and biology (11,9%) are the disciplines that concentrated more studies. Geology and STEM were the object of one and two studies, respectively. A few studies (4,9%) dealt with several disciplines. Primary school studies tend to concentrate on general science. Considering the number of papers in the different periods, an increasing tendency is noted for physics only. Therefore, research efforts should focus on the less researched disciplines (like Geology/Earth Sciences) and the recent STEM area. Research should also be undertaken to get comparative views of the different school levels and disciplines.

Concerning science themes dealt with by studies focusing on conceptual issues (i.e., science learning), there is a variety of themes, some of them common to primary and secondary schools, like plants, animals, kinematics, optics, electricity, thermodynamics, materials, chemical reactions, acids and bases, and rocks. Some studies concentrating on the affective dimension focus on the relationship between lab activities and science, in general (e.g., interest in science), or one of the themes referred to above (e.g., interest, motivation, or attitudes). Argumentation and social interaction were studied within the context of themes like chemical reactions and acids and bases. The science themes addressed are basic themes that may be common to science curricula worldwide. They are complemented with affective themes that are relevant but traditional.

Question 5: What research paradigms were adopted in the research studies reviewed, and to what extent did their aims change over time?

Concerning the research paradigm, 28, 0% of the studies reviewed are qualitative and 68,5% are quantitative studies, the remaining being mixed methods studies. About half of the articles (52, 4%) report on the use of statistical tests, and 14% used descriptive statistics. Comparing the percentage of qualitative and quantitative studies in the different periods, there is a tendency for quantitative research to increase. The majority (104, that is 72,7%) of the articles reviewed report research dealing with lab-based teaching interventions, in one or more groups, approached qualitatively or quantitatively; a part of the 104 studies (28,8%) used inferential statistics to compare groups and assess the effect of the intervention. Qualitative research draws mainly on content analysis of students' productions (e.g., reports) and interactions during group work. A small part of the studies dealing with conceptual learning used statistical analysis to conclude about the impact of the interventions. This fact weakens the research conclusions and the external validity of the studies.

Question 6: What lab-based approaches were addressed in the studies, and to what extent did they change over time?

Of the 104 studies that include teaching interventions, nine papers (8,6%) state that the lab procedure was used to illustrate/confirm concepts or ideas previously taught to students and other 5,8% report on the use of exercises (e.g., to learn how to operate the Bunsen burner or light microscope); many papers (41,3%) report on the use of investigations, 13,5% used guided worksheets leading to the intended result, and 13,5% used POER-based worksheets, to promote students' conceptual change. The remaining do not provide enough information for the reader to ascertain the type of activity used. There is a good level of papers focusing on investigations, but research may show a picture that does not correspond to what is going on in the normal classroom.

Only 13 (out of 104) papers mentioned the use of digital tools (e.g., Arduino, cellular phone, and sensors), and 19 mentioned the use of daily life materials (e.g., toothpaste, bottles, and credit cards), alone or combined with lab materials. Even though it is highly probable that in the other studies, only traditional lab material was used, 25% of the articles involving teaching interventions do not provide clear information on that. In most studies (55,8%), students implemented the procedure in small groups, and in 15,4% they did it individually; about one fourth of the papers (23,1%) do not make it clear who implements the procedure; in the remaining cases (5,8%), it is the teacher or the teacher with some students that do it, as a demonstration for the class. Before 2000, no reference to individual students' implementation of the lab procedure was found; the same applies to implementation by the teacher, after 2012. Assuming that activities continue being performed, this indicates a big role change that leads students to the centre of the teaching and learning process, which seems to be a promising result.

Question 7: What and how were data collected in the studies reviewed?

The majority of the papers reviewed (59,4%) used a single technique to collect data; the remaining used combinations of two, three, or even four techniques: questionnaire/knowledge test, interview, observation, and analysis of documents, namely lab reports. Opinion, motivation, or interest questionnaires and knowledge tests were the types of data collection instruments most used, both in the whole set of reviewed articles (63,6%) and in the subset of papers ($n = 104$) reporting an intervention study (57,7%); 41,3% of the articles reporting an intervention used knowledge tests. Some studies used: interviews to better understand students' opinions about the relationship between lab and science and attitudes towards lab-based classes; observation to study, for instance, students' interaction within small work and with teacher, students' argumentation, and how students perform a lab technique (e.g., dissecting a calf eye); and document analysis, namely lab reports, to study students' argumentative skills, or mastery of scientific methodology. Various techniques were used alone or in combination with two or more techniques; unfortunately, interviews were not used in the intervention studies reviewed. They would enable researchers to go deeper into the issues under study. Also, several intervention studies missed pre-/post-test

and or experimental/control group comparison, which are severe weaknesses of the analysis.

Question 8: What findings were obtained with lab-based intervention studies, and to what extent do they depend on time and school level?

Most studies dealing with science learning (51 out of 58) report positive effects of the lab-based interventions. However, only 13 of them included control and experimental groups, with the experimental groups achieving more conceptual learning, showing more retention, or changing their alternative conceptions in a more extensive way than the control groups, irrespective of school level and period of time. Four (out of 58) studies report negative effects attributed to the resistance to changing the usual lab practice. Most experimental interventions are characterized by student-centred lab use, based on the implementation of activities with different levels of openness (but with the predominance of investigations) that require students to make decisions under the teacher's supervision and guidance; control group interventions include closed worksheet-based activities that guide students to the intended answer. Most studies omit details on the pedagogical approach adopted, which impairs an understanding of the lab procedure and the way it is put into practice, as well as why, for example, there was no difference between groups (two studies) or no evolution (one study).

Almost all studies dealing with procedural knowledge indicate that students learn from investigations (40 out of 43), even though only four of them use an experimental design with a control group. However, they indicate that students show some difficulties in planning lab procedures, manipulating materials (especially in primary school), analysing data, and even following a lab worksheet; no gender differences were reported. The remaining three studies report a negative effect of the interventions on students' procedural learning, which was attributed to the novelty of the investigation-based interventions for students and their lack of procedural knowledge related to planning procedures, using equipment, and analysing data.

Concerning the epistemological dimension, no study reports regression, but the two (out of six) studies that used a control and experimental group design report no evolution. Participants in the single-group studies held traditional views of the nature of science, independent of gender; in constructivist lab environments, they developed an understanding of the central role of ideas in the learning process, and were able to test and revise their ideas. However, details on measurement and the combination of techniques used to collect data are seldom provided, which prevents the reader from making a fair judgment of the robustness of the research reported.

The majority of the studies dealing with the affective dimension (39 out of 43) report positive effects of the interventions on students' opinions, interest, enjoyment, etc. However, only 13 (out of 39) used a research design that enables them to show that students in the experimental groups became more favourable to practical activities, increased their motivation and interest, and improved their attitudes towards science. Two single-group studies report a negative effect of the interventions, caused by students' dislike of performing investigations due to a lack of guidance. Even though

studies show that students tend to enjoy and prefer lab-based approaches over lecture-based ones, they also suggest that older students struggle to see the relevance of laboratory activities to daily life. This means that lab activities may need to be contextualized to make more sense for students.

6.6 Conclusion and Ways Forward

This literature review suggests that researchers' interest in lab-based practical activities as an educational tool for students has been increasing, both in primary and secondary schools. Despite small differences between school levels and periods, researchers report positive effects on learning science, learning about science, and learning how to do science, as well as on the affective dimension. Some studies focusing on the affective dimension used very large samples and relied on data collection procedures consistent with the research problems, which enables their authors to reach a generalizable conclusion; others drew on small samples for a deep understanding and reached their aim; others omitted information relevant to the reader to judge about their internal consistency. A considerable amount of the intervention studies missed pre-/post-test comparison and/or used quite small convenience samples, made of one or a few classes, which reduces their scientific significance even when statistical significance was achieved. Some of those pieces of research also lack detailed information on the teaching approach(s), namely, on the features of the lab activity, who implemented the lab procedure, and whether it was implemented consistently with the intended learning goals (in a few cases, authors assume it was not), or the data collection techniques and instruments and/or conditions they were applied.

Before 2000, few papers were accessible online, a fact that conditioned the analysis of the evolution of the features of the research. The reduced number of studies focusing on primary school also imposes some conditioning on the comparison between school levels. The screening of the articles may have led to some undue exclusion. However, this review suggests that lab-based activities may be a valuable educational tool, especially those with a higher degree of openness, as they have more power to activate students' motivation and to promote integrated learning of the diverse dimensions of science education, given that the teacher provides appropriate guidance (Kirschner et al., 2006) to them, according to school level and students' use to lab activities. Digital technologies, mentioned in a reduced number of studies, should be more present in the school lab. If integrated with traditional lab material, digital technologies may promote students' motivation and educational potential of the lab-based activities, namely for students with disabilities. In this case, success may depend on how technology selection and use match the demands of students' disabilities (Mikropoulos & Iatraki, 2023). In any case, care should be taken to avoid digital technologies transforming lab activities into a sort of black box that overrides natural phenomena. A good balance between traditional lab equipment, digital technology, and everyday materials may strengthen the link between science

and daily life, with digital technologies powering it (Dyrberg et al., 2017; Kluge, 2014) or releasing students from mechanical tasks. Additionally, digital technologies can promote sustainability by reducing the amount of laboratory materials used. However, this should not be done at the expense of developing important manipulative skills, which require hands-on activities. Their integration may promote a more balanced science education while making it inclusive not only for low achievers but also for gifted students, who are often neglected. However, the integration of digital technologies in the school's physical lab needs to be studied in relation to relevant overarching pedagogical approaches and considering the existence of different types of lab activities. Mixed-methods research should be acknowledged to study the impact of that integration, as quantitative approaches provide a big picture, and qualitative approaches allow a deep understanding of how the integration of those technologies can promote students' learning, especially for those with some sort of disability.

It may not be worth doing 'one more study' about students' attitudes, interests, or motivation towards lab activities, but it may be worth understanding why their interest in lab activities tends to decrease with schooling (Sharpe & Abrahams, 2020). The (de)contextualization of lab activities, the relationship between lab activities and assessment practices, including national exams, and higher education admission requirements, may need to be carefully analysed. This may help to reorient physical lab-based practical classes not just to please students but to create a learning environment that uses technologically enriched lab activities when they are valuable for specific and explicit purposes, in such a way that students may perceive their relevance and fully engage in them, with minds, hands, and hearts-on, for the benefit of their science education.

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Supplementary Material

The list of articles reviewed and tables with data that support the findings section are available from <https://doi.org/10.34622/datarepository/Z6IXMH>.

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