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# Implementation of Low-Cost Laboratory in Education: A Systematic Literature Review

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**Abstract.** In developing countries, the need of practical facilities such as teaching aids and laboratories equipment is still a problem in education. This Inadequate laboratory equipment will affect learning outcomes, and the quality of graduates. The high price of commercial equipment is one of the factors. Therefore, there has been a lot of research to develop low-cost laboratory. This article aims to review the development of low-cost laboratory and how they have implemented in learning. The Systematic Literature Review method is used to overview the implementation of low-cost laboratories in the learning. The synthesis of articles refers to the PRISMA 2020 guidelines. The published articles used in this study were obtained from the IEEE Xplore database for publication from 2017 – 2021. After the articles are selected using inclusion and exclusion criteria, 32 articles were obtained for use. The results of this study indicate that a low-cost laboratory can be an alternative solution to the high price of commercial equipment, and as a learning aid to improve learning outcomes. The methods used in implementing low-cost laboratories are design, research and development and experimentation. The use of low-cost laboratories in learning activities shows a positive impact on improving the quality of learning outcomes.

**Keywords**: low-cost laboratory, education, literature review

## INTRODUCTION

In developing countries, the availability of educational facilities and infrastructure is still a problem in educational scope (Prieto et al., 2017). Inadequate facilities in educational institutions (Ekin et al., 2021), disproportionate number of available tools and students (Ong & Ling, 2020; Oteri, 2020; Trabelsi & Saleous, 2019) causing learners to practice in groups(Berman et al., 2021) and the high price of tools or machines that meet industrial standard on the market (Fukumoto et al., 2021) become a burden for schools. Sometimes the commercial equipment available in the market is not suitable for educational purposes (Dias et al., 2020). Strategies for fulfilling laboratory/workshop facilities including optimizing their use by teachers in learning become alternative solutions to improve the quality of learning(Sajidan et al., 2018).

The COVID-19 pandemic that happened had a great impact on the order of social lives. This impact is also affected in education, especially in the learning process. The Social Distancing policy has force students to online learning. They are not be allowed to attend in face-to-face learning at school, including laboratory practice activities (Bekasiewicz et al., 2021). But on the other hand, practicum learning activities cannot be eliminated, especially in vocational lessons (Huertas et al., 2020).

Practice learning is very important in improve the competence of students (Slamnik-Kriještorac et al., 2021). The learning by doing method is able to increase the students understanding for learning materials up to 70%. They doing what they hear and see (Khaing et al., 2018). There are three kinds of practices learning activities, that are Simulation, Emulation and hands-on practice (Uyanik & Catalbas, 2018). laboratory experiments are important to achieve learning objectives and to enrich students' Cognitive, Affective and psychomotor abilities. Through this practical learning activity, the concepts and theories learned in the classroom will be observed and verified by students using real experiments (Firdaus et al., 2019). Learning facilities are one of the factors supporting the success of learning activities (Bima et al., 2021).

Various efforts have been made to overcome the limitations of practical learning in the laboratory in various educational institutions. One of them is the development of low-cost laboratory equipment as an alternative solution for availability of practical equipment and to overcome social distancing policies during the pandemic.. An effective and appropriate learning approach (Lee et al., 2020; Sanfilippo & Austreng, 2018) also be explored so that the quality of learning continues to improve. So, in this study we are trying to explain how the implementation of low-cost laboratories in educational.

Low-cost laboratory are meant laboratory facilities to support practical learning activities developed using simpler equipment, cheaper and more affordable. For example, the use of arduino for a control system in replace of PLC, raspberry pi used for network servers is relatively cheaper than using a computer CPU, Simulation software to simulate the operation of commercial equipment that is very expensive. At a reduced cost, students can conduct experiments similar to commercial laboratory equipment and gain hands-on experience in their learning. These low-cost laboratories such as physical laboratory (learning kit, portable trainer kit), virtual laboratory and remote laboratory.

The purpose of this systematic literature review is to provide an overview of the development and implementation of low-cost laboratory in the learning. We investigate three main points: research methods, the technology used and instructional design. Therefore, the research questions in this study are:

RQ1: What are the research objectives, methods and outcomes in the implementation of low-cost laboratories in education.
RQ2: Which level of education is low-cost laboratory have been implemented
RQ3: What Technology has been used in the development of low-cost laboratories.
RQ4: What instructional design has been applied to low-cost laboratories.

Through this study, we hope that it can motivate teachers and students in developing low-cost laboratories as an alternative solution increase availability of learning facilities at school.

## METHODS

This Systematic literature reviews (SLR) study was carried out to get an overview of the implementation of low-cost laboratories in the learning process. Systematic literature review is a method of synthesizing scientific articles to answer certain research questions transparently and reproducibly, while combining all published articles on related topics as well as assessing the quality of the article (Lame, 2019). The purpose of SLR research is to identify, review, evaluate, and interpret all available research with the topic field of interesting phenomena, with certain relevant research questions (Triandini et al., 2019). The synthesis of articles refers to the PRISMA 2020 guidelines (Page et al., 2021). This guide helps researchers provide transparent and complete reports on SLRs (Chan et al., 2021). The author needs to determine the search strategy, selection criteria, selection procedure, and data collection process.

### Database and Search Keyword

The first step of the SLR is searching literature on the database. Literature search for this study was carried out on the IEEE Xplore database using the term "(low cost OR Afford OR portable) AND (laboratory OR kit) AND (teaching OR learning OR education)" in the Abstract field with publications between 2017 – 2021. This search returned 228 articles.

### Inclusion and Exclusion Criteria

Table 1. Inclusion and Exclusion Criteria

| Inclusion | Exclusion |
|---|---|
| • Journals and Proceedings of the Conference | • Articles are reviews, literature reviews, bibliometrics, manuscripts |

| | |
|---|---|
| • Development of Low-cost laboratory for learning purposes<br>• Published in English<br>• Implemented in learning | • Low-cost development for Industrial purposes, Research,<br>• Publications that are not in English<br>• Low-cost has not been implemented in learning<br>• Full text cannot be downloaded |

The next step is to choose an article that is relevant to the topic included for review. the article selection process refers to PIRSMA 2020. This synthesis stage consists of 4 stages, identification, screening, eligibility and inclusion. Article selection started with screening the article title and abstract and obtained as many as 108 articles. Then continued with full text screening referring to the Inclusion and Exclusion criteria as in Table.1 above so that 32 articles were obtained.

**Data Analysis and Coding**

The final step is to analyze the 32 articles to find information that corresponds to the research questions.

1. Research Methods

   An analysis of the research purpose was to get answers for RQ1 about what are the research purpose of the low-cost laboratory implementation were. In this case we group the research objectives into three categories: Action Research, Experiment, Research and Development.

   Action Research focuses on research to improve learning. Experiment Research focuses on research conducted to try, find and confirm while Research and Development is a research program to develop products used in the world of Education.
2. Research Methods

   At Research Methods stage, an analysis was carried out to answer RQ1 about the methods used in researching the implementation of low-cost laboratories.
3. Research Outcome

   At this stage, an analysis was carried out to answer RQ1 about the research results used in low-cost laboratory implementation research. The variables that appear in the group become three categories Affective, Cognitive and Skill-based.
4. Education Level

   The Level of Education is reviewed to find out at what level this low-cost laboratory research has been applied. The level used refers to the level of formal and informal education.
5. Technology Type

   The review of the types of technology aims to find out what types of low-cost laboratories are used in learning.
6. Instructional Design

   Instructional design is an analysis by identifying learning models that using the low-cost laboratory used in this publication.

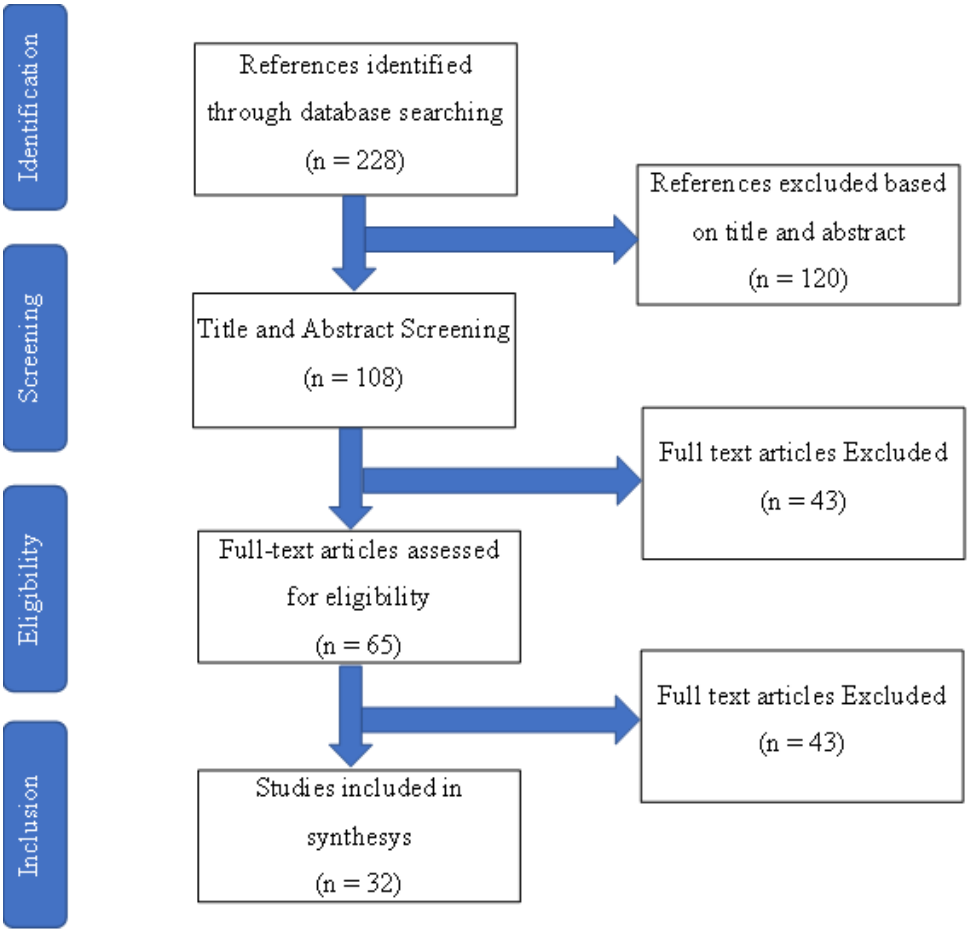


Figure 1. The Prisma Flow Diagram from The Systematic Review Phase in This Study

## RESULTS AND DISCUSSION

This section connects the results of the review inquiry to the three research questions mentioned in Section 2.

### Research Methods

Table 2. The Three Categories of Research Methods with The Corresponding Publications as References

| Research Methods | Number of Articles | References |
|---|---|---|
| Action Research | 8 | 2; 3; 4; 5; 11; 14; 15; 19 |
| Experiment | 12 | 6; 8; 9; 10; 13; 16; 17; 21; 22; 24; 29; 32 |
| Research and Development | 12 | 1; 7; 12; 18; 20; 23; 25; 26; 27; 28; 30; 31 |

Research on low-cost laboratories is still focused on the realm of development and experimentation. In this case, the development of low-cost laboratories (n=12 or 37.5%) is driven by the limited availability of practicum equipment in educational institutions, so it is necessary to find alternative solutions. This limitation is due to the high price of commercial laboratory instruments, sometimes the kits on the market are not suitable for use in institutions. Meanwhile, various experiments were also carried out (n = 12 or 37.5%) to find the right way to use these tools in the learning process, regardless of whether as a learning tool or as a learning medium, especially during the implementation of social distancing in the pandemic period. However, studies to see the results or impact of the implementation of low-cost laboratories on improving the quality of learning (action research) are still less (n = 8 or 25%).

Table 3. The Research Methods Used Accordingly as Existing References

| Research Methods | Number of Articles | Reference |
|---|---|---|
| Experiment | 7 | 4; 13; 14; 16; 19; 28; 30 |
| Exploration | 2 | 8; 10 |
| Comparation | 1 | 2 |
| Quantitative | 1 | 15 |
| Mixed Method | 1 | 11 |
| Quasi-Experiment | 16 | 1; 5; 6; 7; 9; 12; 17; 20; 21; 22; 23; 24; 27; 29; 31; 32 |
| Research and Development | 3 | 18; 25; 26 |
| Triangulation | 1 | 3 |

The Quasi-Experiment method predominates (n=16 or 50%) as a method of reference. In its implementation, this method does not use random assignments but uses existing groups. This method is widely used because researchers do not need to create certain conditions to conduct research. They can take advantage of the students they are teaching to provide feedback on the tools used in learning. Other methods used such as Experimen (n=7 or 22%), R&D (n=3 or 10%), the rest are exploration, comparison, quantitative, triangulation and mixed methods.

**Research Outcomes**

Table 4. An Overview of The Research Outcome Used Accordingly as a Reference to The Existing

| Research Outcome | Number of Articles | Reference |
|---|---|---|
| Affective | 20 | 1; 2; 3; 4; 5; 6; 7; 9; 10; 11; 15; 16; 21; 22; 24; 27; 29; 30; 31; 32 |
| Cognitive | 11 | 2; 3; 5; 6; 7; 8; 12; 15; 19; 21; 22; |
| Skill-based | 26 | 1; 2; 3; 6; 7; 8; 9; 10; 11; 12; 13; 14; 15; 16; 17; 18; 19; 20; 21; 22; 23; 24; 25; 26; 27; 28 |

Most of the studies measure this skill-based aspect (n = 26 or 46%) because most of the studies are carried out with quasi-experiment to see how low-cost labor can be an alternative solution for students to carry out practical activities either in Hands-on practice due to limited facilities or remotely and virtually due to the enactment of social distancing policies during a pandemic even with Project learning. Practicum learning activities in the laboratory are mostly aimed at training and improving the skills of students towards certain jobs, especially in engineering schools. In addition, the study also examined affective aspects (n= 20 or 35%) by asking students for responses in using low-cost laboratories. This feedback can be comfort, motivation, effectiveness, confidence in learning. While the cognitive aspect only 19% (n=11) of the whole does it. Research that measures cognitive aspects is generally carried out if the tool has been used in the course and the learning steps are well planned. Note: in this part of the results, many researchers have examined more than one aspect only.

**Education Level**

Table 5. The Level of Education Used Accordingly as an Existing Reference

| Education Level | Number of Articles | Reference |
|---|---|---|
| Secondary School | 1 | 29 |
| High School | 3 | 3; 8; 26 |
| Undergraduate | 26 | 1; 2; 4; 5; 6; 7; 8; 9; 11; 12; 13; 14; 15; 16; 17; 18; 19; 20; 21; 22; 23; 24; 25; 28; 30; 31; 32 |
| Postgraduate | 2 | 23; 30 |
| College | 1 | 27 |
| Training Course | 1 | 10 |

Most of the research on low-cost laboratories was implemented at the undergraduate university level (n=26 or 76%). As for other levels of education, there are very few. Postgraduate 6% or 2 article, High school 9% or 3 article, secondary school, college and training course 3% each or 1 Article.

**Technology Type**

Table 6. Shows The Type of Technology Used Accordingly as an Existing Reference

| Technology Type | Number of Articles | Reference |
|---|---|---|
| Cloud Laboratory | 1 | 2; |
| Learning Kit | 2 | 3; 11 |
| Physical Laboratory | 12 | 2; 6; 9; 18; 20; 21; 22; 23; 25; 28; 30; 32 |
| Portable kit | 6 | 5; 7; 12; 13; 15; 31 |
| Remote Laboratory | 5 | 1; 4; 10; 16; 17 |
| Virtual Laboratory | 7 | 8; 14; 19; 24; 26; 27; 29; |

Since the development of low-cost laboratories generally aims to provide adequate practicum facilities in educational institutions, the development of physical laboratory types is found in many referenced publications (n = 12 or 37%). After the COVID-19 Pandemic, the development of low-cost laboratories began to shift towards equipment that could support distance learning. So, the development of portable kits (n=6 or 18%), remote laboratories (n=5 or 15%), virtual laboratories (n=7 or 21%) and cloud laboratories (n=1 or 3%) began to be done a lot. In addition, there is also equipment designed as a project for students where students can devote their creativity to the project. Here we term the learning kit discussed through (n=2 or 6%) articles.

**Instructional Design**

Table 7. Shows The Instructive Design Used Accordingly as an Existing Reference

| Instructional Design | Number of Articles | Reference |
|---|---|---|
| Activity Based Learning | 1 | 29 |
| Blended Learning | 1 | 14 |
| Hands-on Experiment | 12 | 5; 6; 7; 9; 13; 15; 20; 21; 23; 28; 31; 32 |
| Online Learning | 1 | 8 |
| Project Based Learning | 7 | 2; 3; 11; 12; 18; 25; 30 |
| Remote Experiment | 5 | 1; 4; 10; 16; 17 |
| Simulation | 4 | 19; 22; 24; 26 |
| Virtual Experiment | 1 | 27 |

From the results of the literature review carried out, the most widely used instructional design is hands-on experiment (n= 12 or 37%) as previously mentioned that the type of equipment that is widely used is the physical laboratory type. Next is the project-based learning design (n= 7 or 21%), remote experiment (n = 5 or 15%) and simulation learning (n = 4 or 12%). For designs such as activity-based learning, blended learning, online learning and virtual experiments, only one article was found each.

**Discussion**

**RQ1. Research Methods for the implementation of low-cost laboratory**

In this study, we found that research on the implementation of low-cost laboratories is generally carried out for the purpose of developing tools as an effort to find solutions to the inadequate of educational facilities and infrastructure in the educational institution. this is due to the high price of practicum equipment on the market (commercial) so that schools cannot afford to provide it in sufficient quantities for each student. Sometimes the equipment on the market is not necessarily suitable for use in the learning process.

Quasi-experiment research is widely carried out to review the impact of the equipment developed on the learning activities it supports and find effective ways to use it so that this equipment can provide learning benefits as expected. Research methods are widely used by researchers where they do not need to design special conditions to test and test the learning tools and methods to be studied. They conduct research on students who take lectures in the courses they teach.

The Skills aspect is the aspect that most appears as a result of research on the implementation of low-cost laboratories. Practicum in the laboratory is mostly aimed at training and improving the skills of students towards certain jobs. However, affective and cognitive aspects are often also involved in research because these three aspects of learning basically go hand in hand. Many research results reveal low-cost equipment created makes users comfortable and confident to use it, increasing interest and motivation in learning. This will also certainly improve student learning outcomes both in terms of skill ability and knowledge.

**RQ2. Education level that implements low-cost laboratory**

The development and implementation of low-cost laboratories is still dominated at the higher education level (universities) there is very little research that discusses the development of low-cost laboratory implementations at the secondary education level. There needs to be research related to the implementation of low-cost laboratories at the secondary education level because the reality is that the problem of limited learning facilities and infrastructure does not only occur at the higher education level (university) but this limitation occurs more in secondary and vocational schools.

**RQ3. Technology that used in implementing low-cost laboratory**

Low-cost based physical equipment as an alternative to expensive commercial equipment still dominates as a technology that is widely implemented in learning. This equipment is generally developed based on arduino, raspberry pi and other simple electronic devices. After the COVID-19 pandemic, low-cost laboratory research began to be heavily directed at supportive development for online learning. The equipment designed is in the form of a virtual laboratory, portable kit and remote laboratory. This is an effort made to provide skill aspects to students in the midst of social restriction policies where students cannot carry out practicum activities directly in the laboratory.

**RQ4. Instructional Design that used in implementing low-cost laboratory in learning**

Instructional design in the form of a direct practicum is commonly found in this study. Many of these instructional designs refer to learning designs using conventional and commercial equipment that are attempted to be implemented in low-cost laboratory-based equipment. However, there are also learning designs made and pursued in accordance with existing conditions and technological developments. That way the existing low-cost laboratory is implemented using a new instructional design and is expected to provide better results and impacts, of course.

## CONCLUSION

The availability of inadequate educational facilities and infrastructure in educational institutions is still a problem in many countries. To fulfill it, it definitely requires a lot of money. The high price of commercial equipment on the market and the large number of students are certainly a burden for the institution. This is further exacerbated by the COVID-19 pandemic that has hit the world in recent years which has caused limited activities in laboratories. This will certainly affect the quality of learning outcomes and graduates, especially in technical and vocational education.

Various studies were conducted to find solutions in reducing this limitation. One of them is research, development and experiments carried out to develop low-cost laboratory equipment which is expected to be an alternative solution. Low-cost laboratory are meant laboratory facilities to support practical

learning activities developed using simpler equipment, cheaper and more affordable. Low-cost laboratories developed such as physical laboratories (learning kits, portable trainer kits), virtual laboratories and remote laboratories. The device is implemented in the learning process in various level of education, from the elementary school, high school, university, college, training courses through hands-on experimental learning, Project based learning, remote experiments, simulations.

The implementation of low-cost laboratories in learning has a positive impact in supporting learning activities and improving the quality of student learning outcomes. This impact is felt on the skill, affective and cognitive aspects because these three aspects of learning basically go hand in hand. Practicum in the laboratory using low-cost equipment mostly shows results that can improve students' skills towards a certain job. The developed tools can be accepted and used by learners well, they become more confident and motivated to do learning activities using these tools and the learning outcomes obtained also show improvement.

**Future Research**

This review identifies studies about investigating low-cost laboratory implementations still being conducted at the undergraduate level. But there are still very few on the other education level. Therefore, it is also necessary to study the implementation of low-cost laboratories at the middle level such as in vocational high schools. In addition, it is necessary to study the instructional design in implementing the low-cost laboratory in the course so that the development and implementation of this low-cost laboratory in education can be duplicated by other educational institutions so that it can also improve the quality of graduates. It is necessary to encourage institutions at other levels to apply the same so that the needs of laboratory practice facilities are also met and teachers are able to carry out learning activities with varied methods.

**Limitation**

The limitations in this literature study are just one database source is used. Because of that there are many publications that should be included in this review may be neglected. Nevertheless, these limitations should not affect our conclusions too much. In addition, the IEEE Xplore database generally contains publications in the field of electronic and electrical engineering. Most of the articles used in this literature study are implementations of low-cost laboratories in the field of electrical engineering.

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