

Role Of Virtual Lab in Inculcating Scientific Attitude & Self Efficacy: Meta Analysis

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ABSTRACT

In this digitized world, the potential of technology in education is beyond our imagination as it has brought a 360-degree revolution to the education system. To achieve promising outcomes, a dire need arises to amalgamate technology with traditional methods of teaching and learning. Both academicians and researchers endorse the use of technology in pedagogy for theory as well as lab-based courses. With the constant tech invasion, it's likely that physical laboratories will lead to an obvious transition into virtual laboratories by facilitating an avant garde experience for students. It can mitigate the high costs of procurement of apparatus in traditional labs and can support distance and blended learning. Researchers have proven that virtual labs help students to save time, effort and keep abreast with the technological development in this digitized era. As per various studies, virtual laboratory enhances critical thinking, scientific attitude, science process skill, self-efficacy, and problem-solving abilities. As per various studies, virtual laboratory enhances critical thinking, scientific attitude, science process skill, self-efficacy, and problem-solving abilities. This meta-analysis is an attempt to observe the impact of virtual laboratories on the scientific attitude and self-efficacy inculcated among students across science subjects and different measurement methods. Key contributions of the study were: 1) 58% of the studies concluded that a virtual laboratory is more effective in developing scientific attitude. 2) 64% of the studies reported that virtual laboratories activities outweigh the physical laboratory activities in creating self-efficacy.

Keywords: Virtual laboratory; Physical laboratory; Self- efficacy; Scientific attitude; Meta analysis,

1. INTRODUCTION

Employment landscape and global ecosystem is quickly changing. It's imperative to focus on the correct method of learning than just to learn. In the present scenario, education is moving towards less content and more experiential learning, which will help learners to be critical thinkers and problem solvers in a novel and continuously changing education system. Pedagogical practices must be improvised to make the learning for theory and lab-based courses more consolidated, creative, innovative, inquiry-driven and joyful.

Experimentation in science promotes discovery and learning. High cost of developing physical laboratory (PL), predicament faced in the maintenance of the lab equipment and non-availability of trained teachers are the major concerns for Laboratory-based courses. Web-based, Video-based, and Virtual laboratories solve the issue to certain extent. Web-enabled and Virtual laboratories are designed for viewing and performing experiments online to kindle the curiosity and inquisitiveness among students. For developing countries, such platforms are a major

solution in dealing with the problem of under-equipped science laboratories and insufficiency of resources. In Today's world, there is lot of emphasis on development of working skills, innovativeness, and critical thinking. Virtual laboratories provide an opportunity to students to develop and sharpen the much-required creativity, competence, and enquiry driven education. Geographical boundaries and distances have become meaningless by introduction of much needed virtual labs (Lynch & Ghergulescu, 2017). The use of virtual laboratory enhances scientific attitude of students by upgrading their critical thinking, creativity, motivation, and science process skills (Ramadhan & Irwanto, 2018). Drastic improvement in conceptual understanding and procedural comprehension of students is reported using virtual laboratory (Kolil et al., 2020). The present study offers to observe the effectiveness of virtual laboratory in generating scientific attitude and self-efficacy among students.

2. REVIEW OF LITERATURE

Virtual Science Laboratory is the vital usage of online practical platforms introduced for the study of experiment-based subjects. Virtual lab is a laboratory experiment-based software, which uses computer and mimic the procedures and operations of the real science laboratory. It synchronizes the theoretical and practical aspects for smooth understanding of concepts (Keller & Keller, 2005). It is also characterized as software-tool that allows users to design repeated experiments to test the effect of variables (Toth, 2016). Virtual Science Lab is a multimedia platform where the learners can collect and operate the apparatus and devices and carryout the experiments through simulations. In biology, virtual microscope provides high resolution images of specimens which are generally not possible to get through the actual microscopes (Waldrop, 2013). Various modes of laboratory delivery including Virtual labs are explored in the study and strength and weakness of e-learning platforms are discussed (Kennepohl, 2021).

It is found that learning of students is improved equally by virtual and hands on laboratory but learning outcome depends on the nature of learning situations of students (Toth, 2016). Hands On Laboratory provides the environment for students to handle the apparatus and the methodology of experiment whereas Virtual Laboratory pays attention to conceptual clarity attained by carrying out simulations (Widodo et al., 2017).

Virtual Labs are effective in making a positive influence on the performance of learners and it helps them in producing the intended results as reported in various research findings. In another study, 16 virtual chemistry experiments were performed by the students, and it was reported that understanding of subject and interest of students was much enhanced using online experimentation (Tüysüz , 2010). Moreover, virtual laboratories are found more efficient for elementary school students in developing a better comprehension and higher academic achievement as compared to hands on laboratory (Sun et al., 2008). One of the findings reported that virtual labs can also be used to perform experiments prior to carry out them in physical labs (Bortnik, 2017). It was concluded that virtual labs have the potential to create mental models even at sub- microscopic level (Herga et al., 2016). The study was conducted on 50 students of grade 10 in physics experiments and reported that physical and virtual mode did not make much of the difference in students' attitude towards the subject however conceptual clarity is more by virtual lab than the physical lab. Fixed reviews were established through various studies regarding the use of virtual laboratories. This study evaluates the impact of virtual laboratory (VL) specifically on scientific attitude and experimental self-efficacy developed among students.

2.1 Scientific Attitude & Virtual Science Laboratory

The most crucial result of science teaching and learning is the development of scientific attitude which enables learners to think logically and rationally. Scientific attitude is a virtue of various traits of a person, and it is generally reflected in one's behaviour and action. There are nine indicators to determine scientific attitudes which are expressed as open-mindedness, reliance on evidence, rationality, confidence in scientific methods, objectivity, aversion to superstitions and willingness to change opinions. A scientific attitude is characterized by collecting and considering facts based on logical and critical thinking. Curious attitude and systematic procedural consistency are also included as important components of scientific attitude (Makransky, 2016).

"Learning by doing" is the motto of modern education system and it is specifically valid for science subjects. All laboratory tools, equipment and techniques add on to the learners' instructions. In addition to this, laboratory methods augment critical thinking, scientific viewpoint and problem-solving abilities. VL provides a platform for the interaction among students and between students and the teacher and upgrade the level of interaction. This kind of unique learning conditions boost the motivation level and attention span of students.

Another study was conducted to see the effect of using Virtual Laboratory on Grade 10 students' attitude towards Physics. It was established statistically that the virtual group students scored high mean score value as compared to the students' performing experiments via physical laboratory. However scientific attitude towards physics was found to be almost the same of two groups (Faour & Ayoubi, 2018). When experiments related to confirmatory tests of anions and cations are conducted then students' level of Science Process Skill mastery is

found better when Physical Lab is used (Ratanum & Osman, 2018). The Study revealed that both virtual and physical laboratory experimentation generate the same level of students' attitude towards chemistry (Ratanum & Osman, 2018). Students expressed their interest in performing physics experiments by virtual mode and positive attitude towards the subject is documented in the study Ghatty, 2013). However, another study documented that though students have +ve attitude towards learning by virtual laboratories but has no impact on students' academic achievement or their attitude towards science (Ambusaidi et al., 2018).

It was also observed that the learners have lost interest in experimentation via physical expository laboratory at high-school and college-level in science courses however the use of emerging technology like virtual labs and simulations were found to be the powerful replacements (Pyatt & Sims, 2007). Students' attitude towards science, academic achievement and retention power also had a positive impact by the application of virtual laboratory (Gambari et al., 2013). The study revealed that students' attitudes toward science and cognitive knowledge were greatly increased in virtual environment (Babaie, 2017; Tüysüz, 2010).

The research findings concluded that PhET interactive simulations have an overall positive impact on students' attitudes and perceptions about learning (Salame & Makki, 2021). The study concluded that a virtual lab is the potential platform to improve the pre laboratory preparations of the students (Dyrberg et al., 2017). The study showed the student's perception that VL can be used to facilitate enhanced study, beyond traditional lab working hours (Chan & Fok, 2009).

This paper reviewed 23 articles on various traits of students' such as ability to think rationally, laboratory skills, and scientific attitudes toward virtual laboratories and reported that virtual laboratory application not only enhanced students' skills to think rationally and find solution for the problems but improved their creativity and comprehension of concepts. In addition to this, it also credited science process skills and motivation. The study further suggested that the use of online experimentation improves the teaching attributes along with students' learning (Irwanto, 2018). Positive impact of virtual lab on students' attitude is again established in physics practicals by conducting semi structured interviews on students in the study (Asiksoy & Islek, 2017). Increased interest and confidence in students using virtual simulations is reported. It also observed long term impact on students' learning due to its flexible access of VL and it allowed students to commit mistakes without fear of accidents (Coleman & Smith, 2019).

A significant and positive correlation was established between the Perceived ease of use (PEU), Motivation (MTV), and Perceived usefulness (PU). It further reported that learners with high motivation and good understanding of virtual platforms intended to get the benefit of using VL in terms of development of attitude towards science (Civril & Ozkul, 2021).

There are few factors like emotional satisfaction, anxiety, intellectual accessibility, interest and utility, and fear which affect the learning outcome of students. All these were taken into consideration and compared before and after the use of virtual laboratory statistically. The study reported that Students' attitude towards chemistry was almost the same (Koehler, 2021). Mobile virtual labs, the ingenious technology also showed strong positive impact on students' attitude towards chemistry subject (Samosa, 2021). Students' attitude towards chemistry and cognitive achievement was measured for different set of students who performed the experiments by virtual and traditional mode. The study formulated that there is strong positive relation between students' attitude and cognitive achievement in both the modes of learning. It indicates that VL is at par with the traditional labs (Larida et al., 2021).

The findings of the study indicate that application of virtual lab helps in comprehension of concrete subjects which further enhances student's interest in the subject and thus adds on to the meaningful learning (Yildirim, 2021). The effectiveness of virtual lab is established by the study as its application upgrades their conceptual understanding, lab skills, motivation, and attitude towards biology. This, cost effective mode of experimentation was also found to create scientific enquiry among students (Byukusenge 2022). Online physics learning was done by LCDS learning media and PBL models and it concluded that curiosity and objectivity of students increased which are the important components of scientific attitude (Ekawati et al., 2023).

2.2 Experimental Self-Efficacy and Virtual Science Laboratory

Self-efficacy is defined as the belief in one's capacity to carry out the desired behaviours to attain specific performance goals (Lev, 1997). Self-efficacy induces confidence in an individual and develops the ability to control one's own behaviour, anxiety, and social environment. Very often students develop anxiety when they are not well equipped with the proper methodology and don't get the expected outcome which finally results in loss of students' interest in the subject. A need was felt to examine the impact of virtual experimentation in science on experimental self-efficacy.

One of the studies reported that the students who have low academic achievement and low self-esteem generally experience inferiority complex and lack of confidence which are major causes of low self-efficacy. It further reported that by using mobile educational app, academic self-efficacy can be improved which further enhances their self-efficacy (Hussain et al., 2021). Researchers emphasized that students should be exposed to

virtual laboratories before exposing them to real experimental world (Kolil et al., 2020). Moreover, it was revealed in one more study that virtual lab and physical lab is equally effective for simple concepts however virtual lab is more effective for difficult concepts when guided inquiry method was used (Husnaini & chen, 2021). The study established a positive change in self-efficacy of students who performed experiments by virtual laboratory (Ghatty, 2013).

An attempt was made to oversee the impact of virtual lab on mosses and ferns. It established a positive impact on critical thinking skills, but scientific attitude of students did not alter appreciably.³⁸ The study reported that students felt more comfortable and confident in operating laboratory equipment after using virtual lab however they did not consider VL, a long-term platform in terms of usage (Dyrberg et al., 2017).

The study suggested that simulation-based learning increased the self-efficacy of students in proportion to their previous knowledge and helped them to understand disease mechanism better (Mihardi et al., 2022). The study was conducted on the topic electrochemistry and concluded that students gained more self-efficacy by using virtual and physical lab than the students using physical lab alone however VL cannot be used as a substitute of PL (Silikhin et al., 2018). The hybrid mode of experimentation i.e., PL and VL have a positive influence on self-efficacy of students as compared to the students using only hands-on laboratory (Nais et al., 2018).

Authors coined a new term- experimental self-efficacy to evaluate the beliefs of learners about performing the experiments. It was determined by 4 factors viz conceptual understanding, procedural complexity, laboratory hazards and lack of sufficient resources. Extremely high improvement was reported in experimental self-efficacy using virtual laboratory by alleviating anxiety caused by fear of not getting accurate result (Kolil et al., 2020). A paradigm shift was observed in mode of experimentation from physical to virtual laboratory and virtual mode of experimentation documented the upgradation in the conceptual clarity and self-efficacy of students (Achuthan, 2018).

Virtual laboratory also reported the increase in self-efficacy of pre-service teachers while making technology-based lesson plan (Kapici & Akcay, 2023). Virtual lab simulations are found to be effective tool in attaining learning achievement and self-efficacy in chemistry. Traditional mode of learning laced with virtual simulations was reported to be the most efficient technology of learning (Peechapol, 2021). The study revealed that Learners with the knowledge of VL develop higher self-efficacy to resolve their problems however there is no change in the self-efficacy of students dealing with circuit analysis (Civril & Ozkul, 2021).

The qualitative study reported that virtual laboratory enhanced students' attitudes and self-efficacy when integrated with traditional mode and VL was used as pre laboratory tool to improve the conceptual understanding of underrepresented minorities (White, 2016). A recent study revealed that COVID-19 situations facilitated the development of ICT efficacy and teaching efficacy as online teaching methods were adopted on a large scale (Yu, 2021). The study contributed to the evidence to support the use of virtual patient simulation on first-year nursing students who have never entered the clinical setting. Despite the students' lack of experience in the clinical setting, the virtual simulation increased their clinical self-efficacy (Comer, 2021). The Study reported that expertise developed post -COVID to use e- learning technology made a significant positive impact on the adoption of electronic and mobile technology (Alammery, 2022).

Academicians and School stakeholders, all over the world agree that virtual mode of communication contributed to smooth teaching learning process by enhancing teacher self-efficacy and high level of reliability on virtual platform. Various online platforms like Google Meet & Zoom facilitated and supported the shift of conventional mode of learning to e – learning technology (Osman, 2020; Pratama et al., 2020). The study indicated that in human anatomy subject, self-motivated students develop self-efficacy using virtual lab which makes them self-regulated (Lonez & Errabo, 2022). The study reported that both conventional and virtual mode of experimentation were at par in terms of self-efficacy when class X performed practical in Simple Harmonic vibration material (Simbolon et al., 2022). The study conducted a pre-test and post-test survey with virtual lab as an intervention and established that intelligent mindset shows higher self-efficacy and self-regulatory behaviour after the use of virtual lab (Peters et al., 2023).

Results of the study found that by using a gamified leader board, students accomplished more complex and difficult tasks smoothly. It further explored that gamified system in virtual environment promised higher self-efficacy (Shadbad et al., 2023) The review analysed that academic self-efficacy of students can be improved by including teachers' message and success and failure of others in the mobile virtual experimental app (Hussain et al., 2021)

3. METHOD

3.1 Meta-Analysis

A meta-analysis is a numerical analysis that unifies the outcomes of numerous research observations. It can be conducted in those cases where there are several technical research done in the past that objectify the exact question. It facilitates the same, by identifying each singular study, that will lead to some error identification. It is the examination of data from several independent studies of the same subject, in order to determine overall trends.

There are various stages of meta-analysis which includes: 1) develop search strategy and locate studies 2) define inclusion and exclusion criteria 3) Selection protocol 4) Data Analysis 5) Result & Discussion 6) Educational implications.

3.2. Develop Search Strategy & Locate Studies

The search engines used in the study to select various research papers were Google Scholar and Scopus database with ScienceDirect. Scopus is the largest collection of abstract and citation database of peer reviewed journals, literature, and conference proceedings. Since Scopus does not provide full paper view, so crossref database was also used. It indexes millions of journal studies which were made free to view and reuse. This provides the additional studies which can be included in the meta-analysis. All these databases are generally used to search research papers. To facilitate the search process, “Virtual Laboratories”, “Virtual Lab” combined with “Scientific Attitude” and “Self-Efficacy” were used as the key words.

3.3. Inclusion and Exclusion Criteria

To analyse the efficiency of virtual laboratory on the scientific attitude and self-efficacy developed among students, meta-analysis was done by selected studies. Initially, all the selected studies were examined by their titles and abstracts. The inclusion criteria of the studies were based on the following basis: 1) All the studies chosen from databases must include virtual laboratories as a treatment. The subjects taken into consideration includes Biology, Chemistry, Physics, medicine, biochemistry, microbiology, pharmaceutical toxicology, human anatomy, electrical & electronic engineering, and science as a whole subject at either postgraduate, undergraduate, or school level. 2) The selected studies must measure either students' self-efficacy or scientific attitude by using virtual laboratory as an intervention. 3) The designated studies must have quasi-experimental or experimental research designs. 4) The studies must provide the essential statistical details to observe the effectiveness of virtual laboratory on self-efficacy and scientific attitude. 5) Only those research papers were selected which were written in English and were published either in a peer-reviewed journal or included in a conference proceeding. The research papers collected for meta-analysis were from year 2010 to 2023. The selection of these years was done because literature reviews were done for earlier years.

Those studies were excluded from the meta-analysis which did not come from a peer-reviewed journal.

Table 1: Summary of included studies for Scientific Attitude

Study (Year)	Sample Size	Subject (Level)
Asiksoy at al. (2017)	42	Physics Laboratory course (Undergraduate)
Ramadhan & Irwanto 2017)	23 article review	Science (All levels)
Ambusaidi et al. (2018)	69	Science (Secondary)
Babaie (2017)	56 students	Physical science (Secondary)
	26 research articles (Biology	Biology (All levels)
Byukusenge et al. (2022)	ed)	
Chan et al. (2015)	50	Electrical & Electronic Engineering (Undergraduate)
Coleman & Smith (2019)	347 & 384 (2 consecutive yr.)	Biochemistry (undergraduate)
Ekawati et al. (2023)	Could not find	Physics (Secondary)
Emily Koehler (2021)	1500	Chemistry (Senior High School)
Faour & Ayoubi (2018)	50	Physics Practicals (Secondary)
Yildirim (2021)	62	Science (Secondary)
Gambari et al. (2013)	56	Physics Practicals (Secondary)
Chemistry (Secondary)	59 STEM students of eleventh grade	Chemistry (Senior Secondary)
Mihard et al. (2022)	100	Science (School level)
Rasyida et al. (2015)	2 classes	Biology (Secondary)
Ratanum et al. (2018)	147	Chemistry (Upper Secondary 4)
Resty C. Samosa (2021)	One group	Chemistry (High School)

Salame et al. (2021)	158	Chemistry (Undergraduate)
TÜYSÜZ1 et al. (2010)	186	Chemistry (9th grade)

Table2: Summary of included studies for self-efficacy

Study (Year)	Sample Size	Subject (Level)
Makransky et al. (2016)	300	Medicine (Undergraduate)
Azham Hussain (2021)	19 papers review	All subjects in general (All levels)
Chattavut Peechapol (2021)	95	Chemistry (Undergraduate)
Darby-White (2016)	60	Chemistry (Undergraduate)
Dyrberg et al. (2016)	73	Microbio & Pharmaceutical (Undergraduate)
Ghatty et al. (2013)	58	Physics (Undergraduate)
Hanife Çivril (2021)	1062	Physics Lab course (High school to PG)
Henrilyn Estoque Loñez (2022)	32	Human Anatomy (Undergraduate)
Husnaini et al. (2019)	68	Science (Secondary)
Kolil et al. (2020)	1225	Chemistry (Undergraduate)
Meg Peters et al. (2023)	157	Science (Undergraduate)
Nais et al. (2018)	74	Chemistry (Senior High School)
Shadbad et al. (2023)	40 * 5 sections	All IS Major subjects (Undergraduate)
Solikhin et al. (2021)	3 classes of grade 12	Chemistry (Senior High School)

3.4. Selection Protocol

The researcher selected various papers for meta-analysis as per the criteria and stages of elimination decided. In the first step, studies were searched from Google Scholar, Scopus & Crossref databases by using specific key words as mentioned earlier. A total of 1017 studies were gathered from records of databases. This selection was done by close examination of their titles and abstracts. 22 studies were found to be duplicate, thereby excluded from the collection. 829 studies were eliminated because the keywords used in them were not suitable. Thorough examination of the abstracts of studies further eliminated 117 studies. At this stage, 49 studies were left. In the next phase of selection of appropriate studies, 9 studies were eliminated because of insufficient data on scientific attitude and self-efficacy whereas 7 were excluded due to lack of statistical information. After intense and thorough examination of all research papers, 33 studies entered the final stage of meta-analysis. The flow chart mentioned below depicts various stages of rigorous and in-depth inspection and selection of studies for meta-analysis.

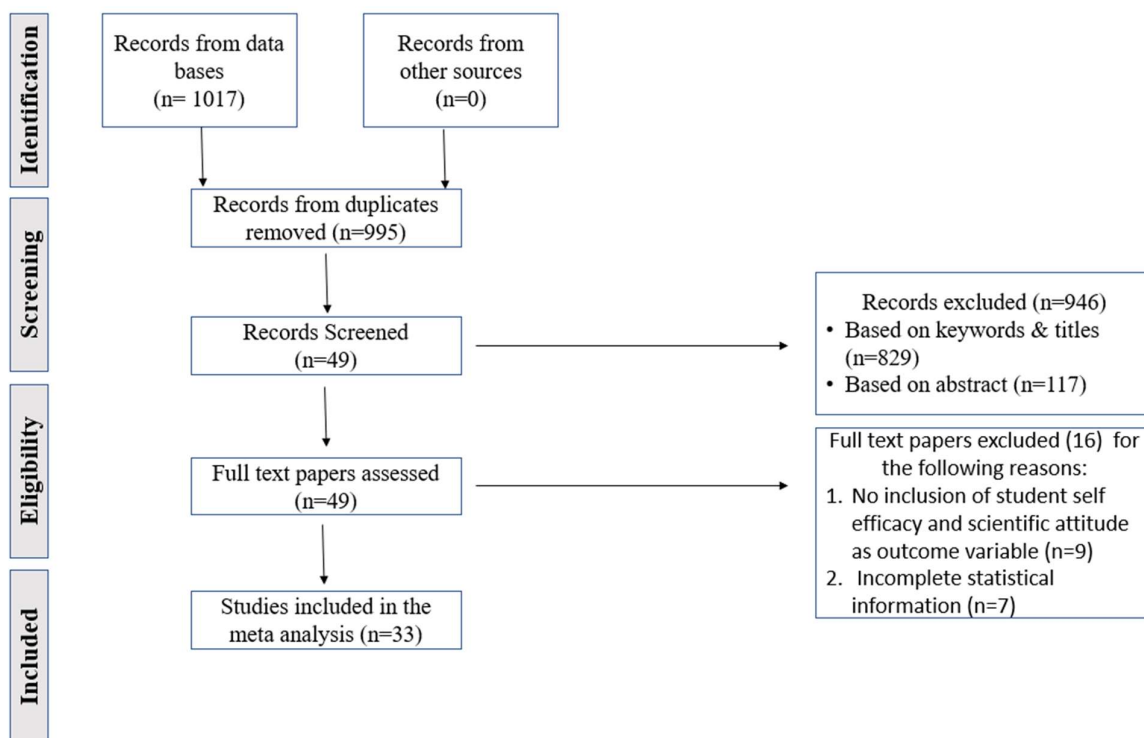


Figure 1: Selection Procedure of Review Articles
Source: Marc Lancer Santos and Maricar Prudente (2018)

3.5. Data Analysis

All the studies selected, were categorized under various heads such as having positive influence, no significant impact/ importance of hybrid mode on scientific attitude and self-efficacy of students' by using virtual laboratory. The percentages of all heads were calculated and shown by bar graphs drawn in figure 1 & 2.

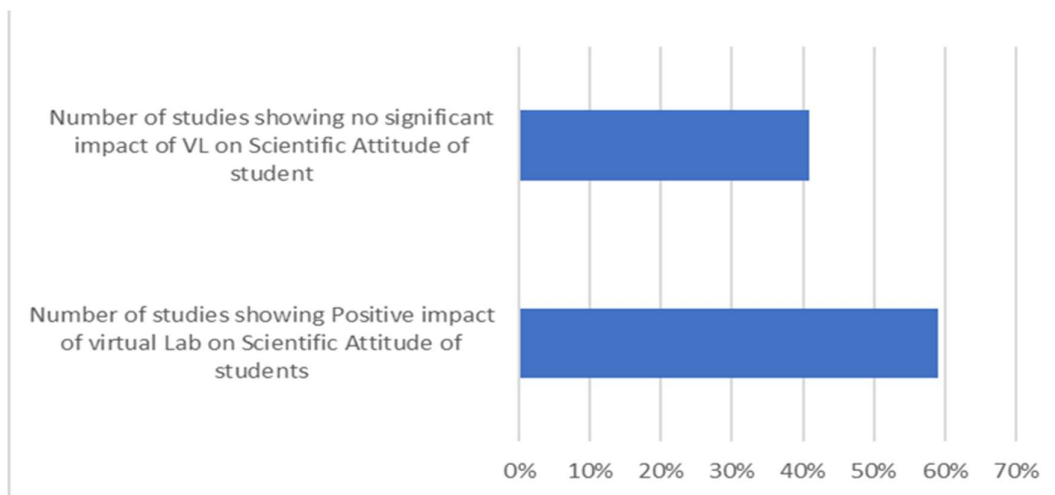


Figure 2: Number of studies depicting role of virtual laboratory on scientific attitude.

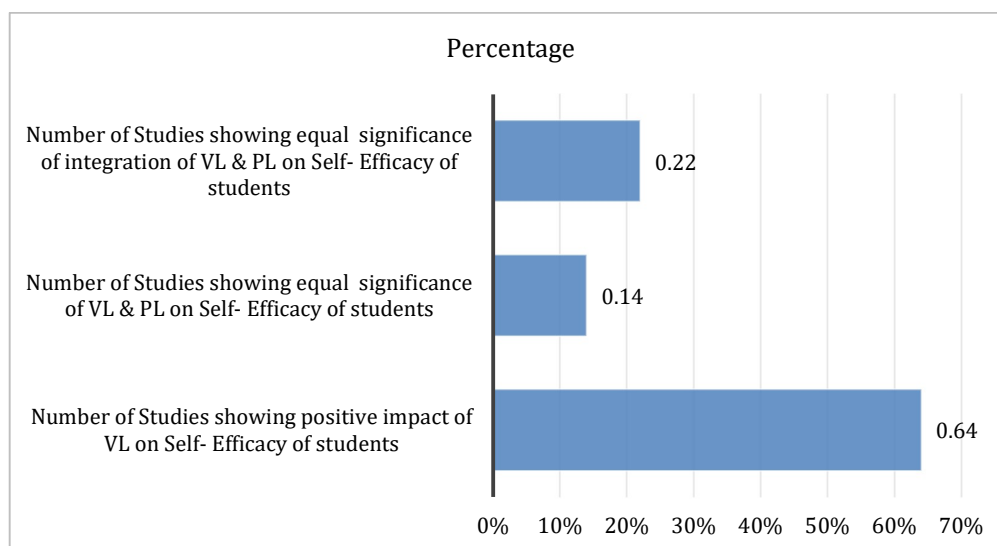


Figure 3: Number of studies depicting role of virtual laboratory on self- efficacy.

4. RESULT & DISCUSSION

There are various factors which affect the development of scientific attitude among students at all educational levels. These includes curiosity, objectivity, open mindedness, logical and critical thinking as suggested by numerous researchers. Science education reaches to the highest level of learning when learner acquires questioning skill and problem-solving potential. Systematic procedural consistency, science process mastery skills and interest in performing experiments are some other traits which contribute to development of scientific attitude especially while performing science laboratory experiments.

Self-efficacy is about believing in one's potential which make a remarkable difference in the learning process. Confidence in one's potential, interest, previous knowledge and understanding of e-learning platform enhances the self-efficacy of students in classroom environment. Anxiety, low self-esteem, inferiority complex, fear of getting wrong results and lack of self-confidence affect it adversely. In the laboratory environment, conceptual understanding, procedural complexity, lab hazards and sufficiency of resources are important indicators of determining self-efficacy.

Initially 1017 papers were selected from various databases. Based on the inclusion criteria of authenticity, appropriateness, availability, and suitable language, 33 papers were chosen for the meta-analysis. Out of these papers, 19 dealt with the role of VL on creating scientific attitude and rest 14 papers expressed the impact of VL in inculcating self-efficacy. All the selected research papers were from various branches of science like Biology, Chemistry, Physics, medicine, biochemistry, microbiology, pharmaceutical toxicology, human anatomy, electrical & electronic engineering, and science as a whole. The selected studies had presented their work from secondary level to post graduate level.

All the selected papers were analysed statistically. It was found that 58% of studies reported positive impact of VL on scientific attitude whereas 42% of studies kept VL at par with the PL. In context of self-efficacy, meta-analysis indicated that 64% of studies established the positive impact of VL, 14% of studies expressed the equal impact of VL and PL and 22% of studies concluded that integration of VL with PL is the best approach in science experimentation. All these values obtained after calculations, were represented by bar graph as shown in figure 1 & 2.

5. CONCLUSION

The meta-analysis conducted in this study revealed that approximately 60% of the reviewed studies support the use of virtual laboratories (VLs) as an effective tool in educational settings. The remaining studies suggest that VLs, whether used in conjunction with physical laboratories (PLs) or independently, perform at par with traditional physical experimentation methods.

At this point, the successful integration and application of multimedia and e-learning technologies, particularly virtual laboratories, in educational practices are influenced by the social environment, learner needs, and the availability of resources. This indicates that the adoption of VLs by educators and students is not merely a matter of technological capability but is also shaped by contextual factors such as institutional support, access

to technology, and pedagogical objectives. As a result, there is significant potential for future research to delve deeper into the optimal use of technology in the teaching-learning process. Further studies could explore how to maximize the benefits of VLS across diverse educational contexts and how to tailor these technologies to meet the specific needs of different learners.

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