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The Effects of Chemistry Virtual Laboratories in Academic Achievement of Secondary Level Learners: A Meta-Analysis

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ABSTRACT

Purpose of the study: Chemistry education is continuously improving to provide appropriate learning for the students. The dynamic shaping of technology in the education induces innovative strategies including the utilization of virtual laboratories. This study explores the topic of examining the effectiveness of virtual laboratories in improving learner's academic achievement in secondary level chemistry.

Methodology: To facilitate the meta-analysis, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol was used. Only 17 studies that met the inclusion criteria were included in the study. Using the Review Manager Version (RevMan) 5.4 software, the standardized mean difference (SMD) was used to measure the effect of virtual laboratory in enhancing learners' achievement.

Main Findings: The meta-analysis discovered the effect size of SMD = 0.98 which can be interpreted as positively large effect size of virtual laboratories in the academic achievement. Sub-groping was also utilized in this study due to the heterogeneous collected data which revealed the effect sizes according to the region, grade level, topic in chemistry, and duration of implementation.

Novelty/Originality of this study: This study aims to synthesize current studies on the use of virtual laboratories in chemistry that focus on secondary-level students. This meta-analysis provides a comprehensive overview for the teachers, researchers, and policy-makers as a basis for the effectiveness of virtual laboratory integration in education. This may help the chemistry instructors design appropriate strategies for utilizing virtual simulations.

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1. INTRODUCTION

Science education is an organized, dynamic, and innovative field that is continuously developing and improving to cater the learning demands of 21st-century learners. One of science education's main goals is to produce scientifically literate learners. Individuals exhibiting scientific literacy, involve the cognitive, social, and emotional aspects [1], to read, understand, and reflect on reliable scientific sources in choosing relevant decisions [2]. Also, Science education intends to foster deep conceptual knowledge and pertinent experiences to serve as an aid for learners in dealing with authentic or real-life problems [3]. Therefore, positive changes in science education highlighting global competitiveness through the implementation of student-centered approaches must be emphasized to ensure the students' acquisition of vital learning competencies. In the K-12 curriculum, one of the major branches of science treated as a core component is chemistry.

Chemistry is the central science that is important due to its fundamental role in our society which connects physical sciences, life sciences, and applied sciences. In addition, knowledge and skills in embedded chemistry are being applied in the food industry, medical field, industrial sector, environmental aspect, and other fields. Despite the numerous benefits to be gained from chemistry education, challenges and problems are continuously faced by educators, learners, and other stakeholders. Constraints in conceptual learning and process acquisition are derived from insufficient instructional materials, conflicting scientific backgrounds, deficient equipment, lack of teacher training, poor supervision, and large class sizes [4]. Due to the many factors, the academic achievement, attitudes, and motivation of students are affected by the various hindrances in chemistry education [5].

Moreover, learning achievement can be characterized as an individual's set of knowledge, skills, and attitudes from a learning process that instructors have organized before the teaching implementation in a determined period. Learning achievement is similar to learning outcomes happening within a learner that involves cognitive, affective, and psychomotor fields that leads to a change in behavior [6]. Factors that may affect students’ achievement are study habits, skills, and attitudes [7]. Moreover, serious efforts must be exerted by the chemistry facilitators in initiating changes, innovations, and integrations in teaching practices to ensure the effective learning process and improvement of learners’ achievement levels [8].

Virtual laboratories are some examples of educational technology tools that produce interactive simulated environments that closely imitate real-world phenomena [9]. The conduction of lessons with the aid of virtual labs fills in the problem of deficiency in chemical equipment and offers more flexibility and induces more learning outcomes compared to traditional laboratories. Another advantage of virtual laboratories is the suitability of the interface to distance learning education because it can be used in a wide range of places and times for virtual experiments [10]. Generally, many innovative methods and approaches in the teaching field may be utilized to integrate with the use of virtual laboratories.

Relevant to the virtual laboratories used in educational settings, related studies show that virtual laboratories are successful in solving the problem including lack of standardized real laboratories and insufficient financial funding for the establishment and maintenance of physical laboratories. The recent educational researches imply that the implementation of science instruction with the aid of virtual laboratories could yield efficacious effects on the scientific learning outcomes of students across different learning areas. In analyzing the general effects of virtual laboratories on academic performance, the systematic review of literature conducted by [11] highlighted chemistry as the subject area which received the highest effect size compared to Biology, Earth Science, and Physics, in terms of the utilization of virtual laboratories in Science education. Virtual laboratories have constructed a progressive effect on the conceptual understanding of learners in chemistry. The study pertaining to the comparison of the effect of traditional method and virtual laboratory intervention garnered a significant positive effect on the learning of chemical equations.

Based on the meta-analysis of [12], a learning process is added when the learner is using technology to support their cognitive abilities while participating in meaningful, active processes. A meta-analysis study sought to address the issues and factors that are related to the use of virtual laboratories focusing on physics education, revealing that virtual laboratories significantly affect student progress; this shows that using virtual simulations in physics training is quite effective [13]. When the studies were grouped by geography, students' grade level, and implementation time, moderator analysis revealed no discernible differences in the effect sizes of the individual investigations [14]. Another meta-analysis explored the impact of virtual laboratories on chemistry, physics, biology, and earth science that focused on the studies conducted between 2015 and 2020, where chemistry has the most significant effect size ($g = 0.787$, $n = 1140$) [11]. Also, in a meta-analysis about the effectiveness of remote and virtual labs on learning in high school STEM education figured out that online labs generally enhance learning to a level that is comparable to that of in-person labs; their impact is amplified when they are incorporated with more conventional teaching methods [15].

Furthermore, in the goal of the educators to the continuous improvement of science education, the construction of a meta-analysis about the proven effective practices in teaching practices will be a great help in summarizing the existing studies regarding the integration of virtual laboratories in teaching science, more specifically, chemistry. To the best of the researcher’s knowledge, there is no existing meta-analytic study regarding the effectiveness of virtual laboratories in enhancing the academic achievement of chemistry students at the secondary level. Therefore, the results from the research will be a guide for the teachers to choose effective teaching strategies to convey maximum learning to their students. The learners' improvement is one of the priorities of educators to attain and implementing student-centered approaches is one of the ways to facilitate efficacious learning. Also, the findings from this study will help the other researchers in their respective studies. This meta-analysis seeks to investigate the effectiveness of virtual laboratories in improving learners’ academic achievement by answering the following questions: 1) How effective is the use of virtual laboratories in improving learners’ academic achievement in chemistry? 2) How do the effect sizes in the included studies have difference in terms of: region; learners’ grade level; topic in chemistry, and; duration of the intervention?

2. RESEARCH METHOD

The methods utilized by this paper are the systematic review and the meta-analysis to search, appraise and explore the measured effectiveness of the virtual laboratories on secondary level students' learning achievement in chemistry. Systematic reviews compile existing literature with the aid of specific search guidelines and then, the selected literature will undergo careful critical appraisal and logical synthesis from different [16]. Moreover, according to [17], a meta-analysis is described as the statistical treatment of the data derived from independent research which are focusing on seeking the answer to the same question, to calculate a quantitative outcome. The steps involved in the meta-analysis are: 1) collating of literature, 2) coding of studies, 3) calculating the effect size, and 4) investigating the moderating effects of the result's description.

Search Protocol

The collected studies in this research are collected manually from these reliable databases: Google Scholar, SCOPUS, Crossref, and Semantic Scholar as arranged in Figure 1. To aid the researcher in retrieving relevant literature, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) have been used [18]. This study began the search for relevant studies from 2017 to 2022 for the collection of recent studies about the use of virtual labs in a specific subject and grade level which is chemistry at the secondary level. The technological intervention was used by the researcher to save resources and time by the means of Harzing's Publish or Perish (PoP) software program to retrieve qualified studies for the meta-analysis [19]. The specific words that were typed in the search engines are virtual laboratories, chemistry, secondary level, achievement, and education. To exhaust the possible qualified literature, the words are interchangeably typed in the databases to ensure that all relevant studies will be included in the meta-analysis.

Inclusion and Exclusion Criteria

A thorough evaluation of the studies is necessary for the quality checking of the literature by inclusion and exclusion criteria. The inclusion criteria in collating journals are: a) must be available in full-text b) must have explicitly state virtual laboratory in chemistry on the title c) must utilize academic achievement as a dependent variable d) must be conducted at a secondary level e) must provide enough statistical data.

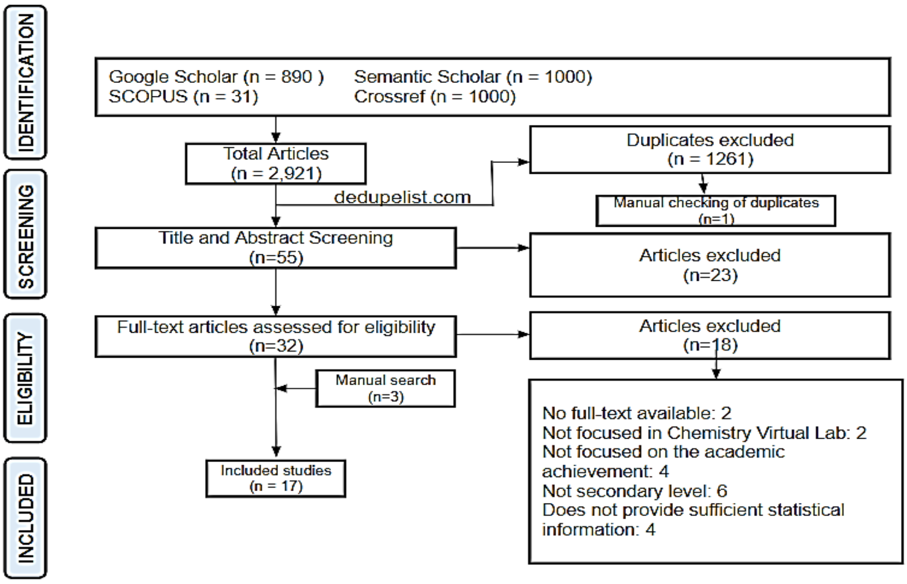

Figure 1. Flowchart of PRISMA literature search model

In Figure 1, the initial number of collected literature peeked up to 2,921 which are primarily reflected by the databases upon typing the keywords. This high amount of literature was decreased to 1,251 by removing 1,660 duplicates through the aid of Dupelist which is an online duplicate removal. Then in the abstract screening, the researcher organized 55 literature qualified for the next screening where 23 studies were excluded while retaining 32 literature for the full-blown review. After the intensive reading of the articles, 18 articles were excluded due to the unmet requirements in the coding procedures. Overall, 17 journals were included in this study which satisfied both inclusion and exclusion protocols.

Coding Procedures

From the studies, pertinent qualitative and quantitative data must be extracted by the researcher. Therefore, the coded relevant data are the following: a) author's name and year of publication b) learner's secondary level (junior high school or senior high school); c) region; d) chemistry subject; e) utilized virtual laboratory; e) comparison condition; and f) outcome measure characteristics.

Effect Size Calculation

According to Nakagawa and Cuthill, the effect size can have different meanings according to the context which includes: 1) an outcome predicting the degree of an effect, 2) actual values derived from effect statistics, 3) pertinent interpretation of an estimated degree of an effect from the effect statistics [20]. This meta-analysis utilized the standardized mean difference which is a summary of quantitative data used when the independent studies test the same results in different ways. The standardized mean difference is not the direct difference in means but it describes the size of the experimental treatment in each literature relative to the standard deviation measured in each study. Effect sizes are from primary studies as a constituent of a larger investigation which is collected and coded to extract effect sizes, styles of intervention, and reporting methods [21]. In some cases, the weighted average values were tabulated by this study due to some journals' report results from multiple experiments, numerous control groups, and varied assessments. The Revier Manager Version 5.4 was utilized for the statistical treatment of the collected data for the meta-analysis.

The researcher applied the random effects model due to the high level of heterogeneity of the studies subjected to the main effect and sub-grouping investigation of the collated effect size. To further investigate the appropriateness of using random effects models in this study, homogeneity statistic I2 was applied in this paper. A measure of negative values of I2 implies an absence of heterogeneity but the descriptors low, moderate, and high refer to upper limits of 25%, 50%, and 75% I2 calculations. The Chi-square test was utilized for the total heterogeneity test while Kendall's tau coefficient was used to predict the relationship between sample size and effect size [22].

3. RESULTS AND DISCUSSION

Out of the 2,921 articles primarily reviewed from databases, only 17 literature met the inclusion criteria to be used in this study. As can be seen in Table 1, the included journals, authors, year of publication, grade level, duration, research design, type of virtual simulation used, and statistical data showing the difference between experimental and control groups are presented as a summary.

Table 1. Summary of the Included Literature

Authors/s amd Year of Publication	Region	Grade Level	Duration	Research Design	Virtual Simulation Tool/s Used	Experimental			Conventional		
						Mean	SD	n	Mean	SD	n
Ahmad et al. (2021)	Asia (Malaysia)	JHS (Electrochemistry)	not reported	QE	Interactive Electrolysis of Aqueous Solution (IEAS)	16.42	2.45	31.00	14.94	2.70	31.00
Aldosari et al. (2022)	Asia (Saudi Arabia)	JHS (Molecular Chemistry)	Not reported	QE	Molecular visualization with Leap motion controller	11.23	2.10	26.00	8.03	2.75	30.00
Ambusaidi et al. 2018 [27]	Asia (Oman)	JHS (General Chemistry)	12 weeks	QE	Crocodile virtual lab	12.79	5.68	34.00	13.74	4.46	35.00
Chado et al. (2021)	Africa (Nigeria)	SHS (Stoichiometry)	2 weeks	TE	unspecified	7.20	3.64	59.00	5.93	2.58	60.00
Chen & Liu (2018)	Asia (Taiwan)	JHS (Chemical Kinetics)	16 weeks	QE	Elements 4 Application	48.58	17.58	53.00	15.49	6.10	51.00
Hodges et al. (2018)	North America (USA)	JHS (Stoichiometry)	Not reported	MM	Redox reaction simulator, Blended Reality Environment (BRE)	8.67	3.18	184.00	6.50	2.18	167.00
Jabeen & Afzal (2020)	Asia (Pakistan)	JHS (General Chemistry)	3 weeks	QE	unspecified	12.19	1.67	58.00	10.13	1.60	57.00
Jornales (2019)	Asia (Philippines)	SHS (General Chemistry)	4 weeks	TE	Phet Simulations	31.27	7.54	30.00	30.03	8.60	30.00
Mihindo et al. (2017)	Africa (Kenya)	JHS (Electrochemistry)	Not reported	QE	unspecified	0.69	0.15	43.00	0.51	0.17	43.00
Nkemakola	Africa	SHS (Chemical	4 weeks	QE	Phet Simulations	57.21	5.53	38.00	41.40	7.66	40.00

Authors/s amd Year of Publication	Region	Grade Level	Duration	Research Design	Virtual Simulation Tool/s Used	Experimental			Conventional		
						Mean	SD	n	Mean	SD	n
m (2018)	(Nigeria)	Kinetics)									
Nuić & Glažar (2019)	Europe (Bosnia and Herzegovina)	JHS (Molecular Chemistry)	not reported	QE	COMPUTER ASSISTED INSTRUCTION (CAI)	9.90	2.39	39.00	9.40	2.89	48.00
Odewumi (2019)	Africa (Nigeria)	SHS (General Chemistry)	6 weeks	QE	Laboratory Software Package	33.00	5.38	14.00	35.00	5.00	14.00
Oladejo, et al. (2021)	Africa (Nigeria)	SHS (Electrochemistry)	4 weeks	QE	COMPUTER ASSISTED INSTRUCTION (CAI)	12.77	2.00	44.00	9.38	2.36	39.00
Ratamun & Osman (2018)	Asia (Malaysia)	SHS (Inorganic Chemistry)	Not reported	QE	unspecified	4.26	0.66	76.00	4.13	0.65	71.00
Şeker & Kartal (2017)	Eurasia (Turkey)	JHS (General Chemistry)	8 weeks	TE	Adobe flash	11.65	3.18	23.00	10.39	2.62	23.00
Suleman	Eurasia (Pakistan)	JHS (General Chemistry)			COMPUTER ASSISTED INSTRUCTION (CAI)	88.29	3.38	25.00	72.36	3.49	25.00
Winkelmann et al. (2019)	North America (USA)	SHS (General Chemistry)	8 weeks	QE	Second Life	7.00	1.00	138.00	6.90	1.00	141.00

Overall, the learners who underwent control and experimental groups are 916 and 904, respectively with a total of 1,820 students. Regarding the site of implementation, eight interventions were held in Asia (n=8), five studies came from Africa (n=5), one result each from Eurasia (n=1) and Europe (n=1), and two outcomes from North America (n=2). The majority of the students who were part of the intervention belonged to the Junior High School (JHS) (n=10) while the seven studies involved Senior High School learners (n=7). The field of Chemistry investigated in each study involved eight General Chemistry (n=8), three applications of Electrochemistry (n=3), two explorations of Molecular Chemistry (n=2), two expansions of Stoichiometry (n=2), and two inquiries of Chemical Kinetics (n=2). Regarding the period of implementation, most of the studies were not able to report the duration of implementation (n=7), while four studies each were held for four to six weeks (n=4) and more than seven weeks (n=4), and the remaining two studies were conducted for one to three weeks (n=2). Experimental designs used were mostly quasi-experimental (n=13), three true experimental (n=3), and one mixed-method design (n=1). The virtual simulations applied were Interactive Electrolysis of Aqueous Solution (IEAS), Molecular visualization with a Leap motion controller, Elements 4 Application, Crocodile virtual lab, Redox reaction simulator, Blended Reality Environment (BRE), Phet Simulations, Laboratory Software Package, Second Life, Adobe flash, Computer Assisted Instruction (CAI) and others were unspecified.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Ahmad et al. (2021)	16.42	2.45	31	14.94	2.7	31	5.9%	0.57 [0.06, 1.08]
Aldosari et al. (2022)	11.23	2.1	26	8.03	2.75	30	5.7%	1.28 [0.70, 1.86]
Ambusaidi et al. (2018)	13.74	4.46	34	12.79	5.68	34	6.0%	0.18 [-0.29, 0.66]
Chado et al. (2021)	7.2	3.64	59	5.93	2.58	60	6.2%	0.40 [0.04, 0.76]
Chen & Liu (2018)	48.58	17.58	53	15.49	6.1	51	5.9%	2.48 [1.96, 2.99]
Hodges et al. (2018)	8.67	3.18	184	6.5	2.18	167	6.5%	0.79 [0.57, 1.00]
Jabeen & Afzal (2020)	12.19	1.67	58	10.13	1.6	57	6.2%	1.25 [0.85, 1.65]
Jornales (2019)	31.27	7.54	30	30.03	8.6	30	5.9%	0.15 [-0.36, 0.66]
Mihindo et al. (2017)	0.69	0.15	43	0.51	0.17	43	6.0%	1.11 [0.66, 1.57]
Nkemakolam (2018)	57.21	5.53	38	41.4	7.66	40	5.7%	2.33 [1.75, 2.92]
Nuić & Glažar (2019)	9.9	2.39	39	9.4	2.89	48	6.1%	0.19 [-0.24, 0.61]
Odewumi (2019)	35	5	14	33	5.38	14	5.2%	0.37 [-0.37, 1.12]
Oladejo, et al. (2021)	12.77	2	44	9.38	2.36	39	5.9%	1.54 [1.05, 2.04]
Ratamun & Osman (2018)	4.26	0.66	76	4.13	0.65	71	6.3%	0.20 [-0.13, 0.52]
Şeker & Kartal (2017)	11.65	3.18	23	10.39	2.62	23	5.7%	0.43 [-0.16, 1.01]
Suleman et al. (2017)	88.29	3.38	25	72.36	3.49	25	4.2%	4.56 [3.48, 5.65]
Winkelmann et al. (2019)	7	1	138	6.9	1	141	6.5%	0.10 [-0.14, 0.33]
Total (95% CI)			**915**			**904**	**100.0%**	**0.98 [0.62, 1.35]**

Heterogeneity: $Tau^2 = 0.52$; $Chi^2 = 204.27$, df = 16 ($P < 0.00001$); $I^2 = 92\%$
Test for overall effect: $Z = 5.27$ ($P < 0.00001$)

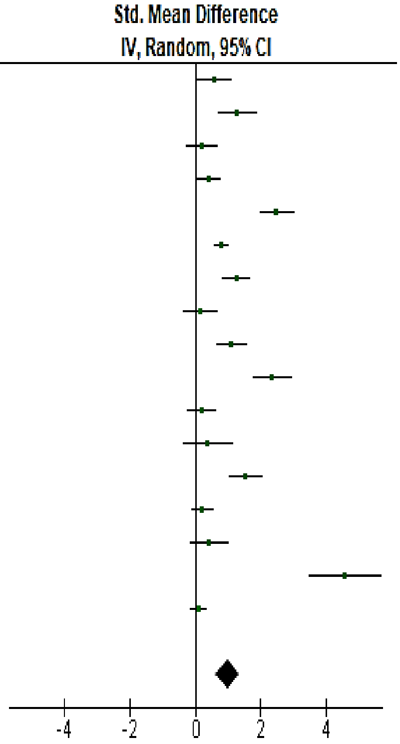

Figure 2. Forest Plot presenting the distribution of effect sizes of the individual studies

As can be gleaned from Figure 2, overall as represented by SMD = 0.98, there is a higher value for the experimental groups compared to control groups regarding the effects of the Chemistry virtual laboratory on learning achievement. The largest effect size (SMD = 4.56) was recorded by [37]. On the contrary, the lowest effect size has the value of SMD = 0.10 as concluded by [38].

The heterogeneity of all the included studies has the value of $I^2 = 92\%$, which can be interpreted that the collated journals have high heterogeneity. The high level of heterogeneity suggests the implication for utilization of a sub-grouping analysis. In this research, the following were analyzed further: the region of implementation, type of Chemistry topic, grade level, duration.

Region of Implementation

This meta-analysis compared the region of implementation of the chemistry virtual laboratories where the interventions were conducted as categorized by the relative continents where the country of implementation is located which are: Africa, Asia, Eurasia, Europe, and North America.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
4.1.1 Asia								
Ahmad et al. (2021)	16.42	2.45	31	14.94	2.7	31	5.9%	0.57 [0.06, 1.08]
Aldosari et al. (2022)	11.23	2.1	26	8.03	2.75	30	5.7%	1.28 [0.70, 1.86]
Chen & Liu (2018)	48.58	17.58	53	15.49	6.1	51	5.9%	2.48 [1.96, 2.99]
Ambusaidi et al. (2018)	13.74	4.46	35	12.79	5.68	34	6.0%	0.18 [-0.29, 0.66]
Hussain et al. (2017)	88.29	3.38	25	72.36	3.49	25	4.2%	4.56 [3.48, 5.65]
Jabeen & Afzal (2020)	12.19	1.67	58	10.13	1.6	57	6.2%	1.25 [0.85, 1.65]
Jornales (2019)	31.27	7.54	30	30.03	8.6	30	5.9%	0.15 [-0.36, 0.66]
Ratamun & Osman (2018)	4.26	0.66	76	4.13	0.65	71	6.3%	0.20 [-0.13, 0.52]
Subtotal (95% CI)			**334**			**329**	**46.1%**	**1.25 [0.53, 1.97]**
Heterogeneity: Tau² = 0.99; Chi² = 120.95, df = 7 (P < 0.00001); I² = 94%								
Test for overall effect: Z = 3.41 (P = 0.0007)								
4.1.2 Africa								
Chado et al. (2021)	7.2	3.64	59	5.93	2.58	60	6.2%	0.40 [0.04, 0.76]
Mihindo et al. (2017)	0.69	0.15	43	0.51	0.17	43	6.0%	1.11 [0.66, 1.57]
Nkemakolam (2018)	57.21	5.53	38	41.4	7.66	40	5.7%	2.33 [1.75, 2.92]
Odewumi (2019)	35	5	14	33	5.38	14	5.2%	0.37 [-0.37, 1.12]
Oladejo, et al. (2021)	12.77	2	44	9.38	2.36	39	5.9%	1.54 [1.05, 2.04]
Subtotal (95% CI)			**198**			**196**	**29.1%**	**1.15 [0.46, 1.85]**
Heterogeneity: Tau² = 0.55; Chi² = 38.04, df = 4 (P < 0.00001); I² = 89%								
Test for overall effect: Z = 3.26 (P = 0.001)								
4.1.3 Eurasia								
Şeker & Kartal (2017)	11.65	3.18	23	10.39	2.62	23	5.7%	0.43 [-0.16, 1.01]
Subtotal (95% CI)			**23**			**23**	**5.7%**	**0.43 [-0.16, 1.01]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.42 (P = 0.15)								
4.1.4 Europe								
Nuić & Glažar (2019)	9.9	2.39	39	9.4	2.89	48	6.1%	0.19 [-0.24, 0.61]
Subtotal (95% CI)			**39**			**48**	**6.1%**	**0.19 [-0.24, 0.61]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.86 (P = 0.39)								
4.1.5 North America								
Hodges et al. (2018)	8.67	3.18	184	6.5	2.18	167	6.5%	0.79 [0.57, 1.00]
Winkelmann et al. (2019)	7	1	138	6.9	1	141	6.5%	0.10 [-0.14, 0.33]
Subtotal (95% CI)			**322**			**308**	**13.0%**	**0.45 [-0.23, 1.12]**
Heterogeneity: Tau² = 0.22; Chi² = 17.73, df = 1 (P < 0.0001); I² = 94%								
Test for overall effect: Z = 1.29 (P = 0.20)								
Total (95% CI)			**916**			**904**	**100.0%**	**0.98 [0.62, 1.35]**
Heterogeneity: Tau² = 0.52; Chi² = 204.33, df = 16 (P < 0.00001); I² = 92%								
Test for overall effect: Z = 5.27 (P < 0.00001)								
Test for subgroup differences: Chi² = 9.69, df = 4 (P = 0.05), I² = 58.7%								

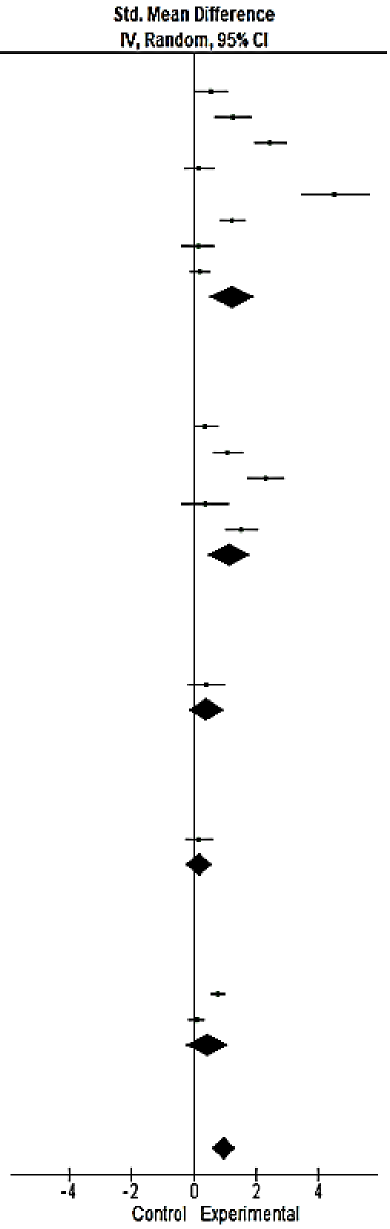

Figure 3. Region subgrouping of the studies

The summary of studies based on the region of implementation were presented in Figure 3. As can be inferred from Figure 3, among all the included regions, the majority of the interventions yielded the highest effect size (SMD = 1.25) from Asia, followed by Africa (SMD = 1.15), then North America (SMD = 0.45), and Eurasia (SMD = 0.43), with Europe as the region with the lowest effect size (SMD = 0.19).

Grade Level

As a sub-group, this study also made a comparison between the grade levels of the participants such as Junior High School [51] and Senior High School level of learners who were subjected to the interventions of virtual laboratories in chemistry.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
5.1.2 Senior High School								
Chado et al. (2021)	7.2	3.64	59	5.93	2.58	60	6.2%	0.40 [0.04, 0.76]
Jornales (2019)	31.27	7.54	30	30.03	8.6	30	5.9%	0.15 [-0.36, 0.66]
Nkemakolam (2018)	57.21	5.53	38	41.4	7.66	40	5.7%	2.33 [1.75, 2.92]
Odewumi (2019)	35	5	14	33	5.38	14	5.2%	0.37 [-0.37, 1.12]
Oladejo, et al. (2021)	12.77	2	44	9.38	2.36	39	5.9%	1.54 [1.05, 2.04]
Ratamun & Osman (2018)	4.26	0.66	76	4.13	0.65	71	6.3%	0.20 [-0.13, 0.52]
Winkelmann et al. (2019)	7	1	138	6.9	1	141	6.5%	0.10 [-0.14, 0.33]
Subtotal (95% CI)			**399**			**395**	**41.8%**	**0.71 [0.17, 1.24]**
Heterogeneity: Tau² = 0.46; Chi² = 71.43, df = 6 (P < 0.00001); I² = 92%								
Test for overall effect: Z = 2.60 (P = 0.009)								
5.1.3 Junior High School								
Ahmad et al. (2021)	16.42	2.45	31	14.94	2.7	31	5.9%	0.57 [0.06, 1.08]
Aldosari et al. (2022)	11.23	2.1	26	8.03	2.75	30	5.7%	1.28 [0.70, 1.86]
Ambusaidi et al. (2018)	13.74	4.46	35	12.79	5.68	34	6.0%	0.18 [-0.29, 0.66]
Chen & Liu (2018)	48.58	17.58	53	15.49	6.1	51	5.9%	2.48 [1.96, 2.99]
Hodges et al. (2018)	8.67	3.18	184	6.5	2.18	167	6.5%	0.79 [0.57, 1.00]
Jabeen & Afzal (2020)	12.19	1.67	58	10.13	1.6	57	6.2%	1.25 [0.85, 1.65]
Mihindo et al. (2017)	0.69	0.15	43	0.51	0.17	43	6.0%	1.11 [0.66, 1.57]
Nuić & Glažar (2019)	9.9	2.39	39	9.4	2.89	48	6.1%	0.19 [-0.24, 0.61]
Şeker & Kartal (2017)	11.65	3.18	23	10.39	2.62	23	5.7%	0.43 [-0.16, 1.01]
Suleman et al. (2017)	88.29	3.38	25	72.36	3.49	25	4.2%	4.56 [3.48, 5.65]
Subtotal (95% CI)			**517**			**509**	**58.2%**	**1.18 [0.69, 1.68]**
Heterogeneity: Tau² = 0.57; Chi² = 110.12, df = 9 (P < 0.00001); I² = 92%								
Test for overall effect: Z = 4.65 (P < 0.00001)								
Total (95% CI)			**916**			**904**	**100.0%**	**0.98 [0.62, 1.35]**
Heterogeneity: Tau² = 0.52; Chi² = 204.33, df = 16 (P < 0.00001); I² = 92%								
Test for overall effect: Z = 5.27 (P < 0.00001)								
Test for subgroup differences: Chi² = 1.63, df = 1 (P = 0.20), I² = 38.8%								

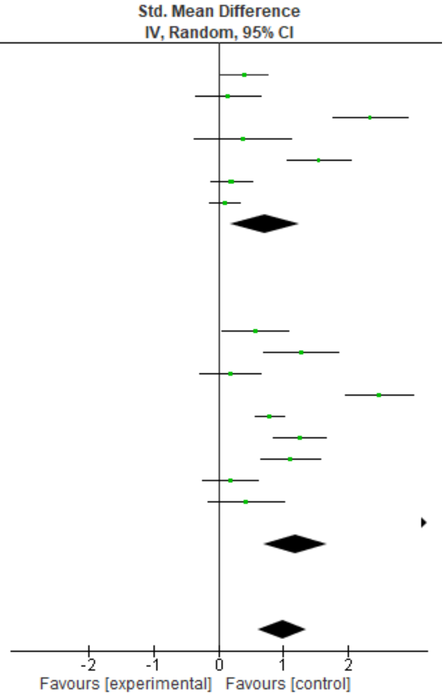

Figure 4. Grade Level subgrouping of the studies

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
5.2.1 Chemical Kinetics								
Chen & Liu (2018)	48.58	17.58	53	15.49	6.1	51	5.9%	2.48 [1.96, 2.99]
Nkemakolam (2018)	57.21	5.53	38	41.4	7.66	40	5.7%	2.33 [1.75, 2.92]
Subtotal (95% CI)			**91**			**91**	**11.6%**	**2.41 [2.03, 2.80]**
Heterogeneity: Tau² = 0.00; Chi² = 0.13, df = 1 (P = 0.72); I² = 0%								
Test for overall effect: Z = 12.27 (P < 0.00001)								
5.2.2 Electrochemistry								
Ahmad et al. (2021)	16.42	2.45	31	14.94	2.7	31	5.9%	0.57 [0.06, 1.08]
Mihindo et al. (2017)	0.69	0.15	43	0.51	0.17	43	6.0%	1.11 [0.66, 1.57]
Oladejo, et al. (2021)	12.77	2	44	9.38	2.36	39	5.9%	1.54 [1.05, 2.04]
Subtotal (95% CI)			**118**			**113**	**17.9%**	**1.08 [0.54, 1.61]**
Heterogeneity: Tau² = 0.16; Chi² = 7.31, df = 2 (P = 0.03); I² = 73%								
Test for overall effect: Z = 3.94 (P < 0.0001)								
5.2.3 General Chemistry								
Ambusaidi et al. (2018)	13.74	4.46	35	12.79	5.68	34	6.0%	0.18 [-0.29, 0.66]
Jabeen & Afzal (2020)	12.19	1.67	58	10.13	1.6	57	6.2%	1.25 [0.85, 1.65]
Jornales (2019)	31.27	7.54	30	30.03	8.6	30	5.9%	0.15 [-0.36, 0.66]
Odewumi (2019)	35	5	14	33	5.38	14	5.2%	0.37 [-0.37, 1.12]
Ratamun & Osman (2018)	4.26	0.66	76	4.13	0.65	71	6.3%	0.20 [-0.13, 0.52]
Şeker & Kartal (2017)	11.65	3.18	23	10.39	2.62	23	5.7%	0.43 [-0.16, 1.01]
Suleman et al. (2017)	88.29	3.38	25	72.36	3.49	25	4.2%	4.56 [3.48, 5.65]
Winkelmann et al. (2019)	7	1	138	6.9	1	141	6.5%	0.10 [-0.14, 0.33]
Subtotal (95% CI)			**399**			**395**	**46.0%**	**0.77 [0.22, 1.31]**
Heterogeneity: Tau² = 0.53; Chi² = 83.46, df = 7 (P < 0.00001); I² = 92%								
Test for overall effect: Z = 2.76 (P = 0.006)								
5.2.4 Molecular Chemistry								
Aldosari et al. (2022)	11.23	2.1	26	8.03	2.75	30	5.7%	1.28 [0.70, 1.86]
Nuić & Glažar (2019)	9.9	2.39	39	9.4	2.89	48	6.1%	0.19 [-0.24, 0.61]
Subtotal (95% CI)			**65**			**78**	**11.8%**	**0.71 [-0.36, 1.78]**
Heterogeneity: Tau² = 0.53; Chi² = 8.89, df = 1 (P = 0.003); I² = 89%								
Test for overall effect: Z = 1.31 (P = 0.19)								
5.2.5 Stoichiometry								
Chado et al. (2021)	7.2	3.64	59	5.93	2.58	60	6.2%	0.40 [0.04, 0.76]
Hodges et al. (2018)	8.67	3.18	184	6.5	2.18	167	6.5%	0.79 [0.57, 1.00]
Subtotal (95% CI)			**243**			**227**	**12.8%**	**0.62 [0.25, 1.00]**
Heterogeneity: Tau² = 0.05; Chi² = 3.21, df = 1 (P = 0.07); I² = 69%								
Test for overall effect: Z = 3.25 (P = 0.001)								
Total (95% CI)			**916**			**904**	**100.0%**	**0.98 [0.62, 1.35]**
Heterogeneity: Tau² = 0.52; Chi² = 204.33, df = 16 (P < 0.00001); I² = 92%								
Test for overall effect: Z = 5.27 (P < 0.00001)								
Test for subgroup differences: Chi² = 50.06, df = 4 (P < 0.00001), I² = 92.0%								

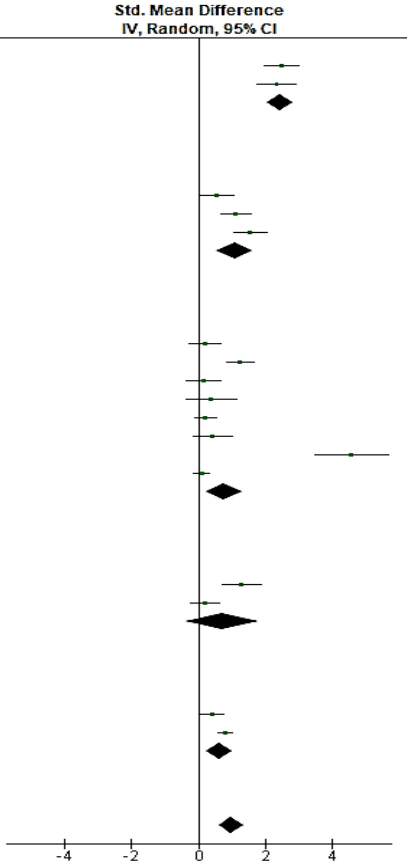

Figure 5. Chemistry Topic Subgrouping of the studie

From Figure 4, it can be seen that studies that involve Junior High School learners have resulted in a greater effect size (SMD = 1.18) compared to the Senior High School level which yielded a lower standard mean difference value (SMD = 0.71).

Topic in Chemistry

To further investigate the effect size of virtual laboratories in chemistry, the focused topic in each intervention was analyzed. Based on Figure 5, Chemical Kinetics yielded the greatest effect size (SMD = 2.41) among the topics utilized in the interventions to be followed by Electrochemistry (SMD = 1.08), General Chemistry (SMD = 0.77) , Molecular Chemistry (SMD = 0.71) , and Stoichiometry (SMD = 0.62).

Duration of Implementation

The duration of implementation pertains to the period of the exposure of learners to the interventions. The ranges of the duration of implementation are grouped as one to three weeks, four to six weeks, more than seven weeks, and not reported.

	Experimental			Control				Std. Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
5.3.1 1-3 weeks								
Chado et al. (2021)	7.2	3.64	59	5.93	2.58	60	6.2%	0.40 [0.04, 0.76]
Jabeen & Afzal (2020)	12.19	1.67	58	10.13	1.6	57	6.2%	1.25 [0.85, 1.65]
Subtotal (95% CI)			**117**			**117**	**12.4%**	**0.82 [-0.01, 1.65]**
Heterogeneity: Tau² = 0.32; Chi² = 9.50, df = 1 (P = 0.002); I² = 89%								
Test for overall effect: Z = 1.93 (P = 0.05)								
5.3.2 4-6 weeks								
Jornales (2019)	31.27	7.54	30	30.03	8.6	30	5.9%	0.15 [-0.36, 0.66]
Nkemakolam (2018)	57.21	5.53	38	41.4	7.66	40	5.7%	2.33 [1.75, 2.92]
Odewumi (2019)	35	5	14	33	5.38	14	5.2%	0.37 [-0.37, 1.12]
Oladejo, et al. (2021)	12.77	2	44	9.38	2.36	39	5.9%	1.54 [1.05, 2.04]
Subtotal (95% CI)			**126**			**123**	**22.8%**	**1.11 [0.10, 2.11]**
Heterogeneity: Tau² = 0.96; Chi² = 37.38, df = 3 (P < 0.00001); I² = 92%								
Test for overall effect: Z = 2.16 (P = 0.03)								
5.3.3 More than 7 weeks								
Ambusaidi et al. (2018)	13.74	4.46	35	12.79	5.68	34	6.0%	0.18 [-0.29, 0.66]
Chen & Liu (2018)	48.58	17.58	53	15.49	6.1	51	5.9%	2.48 [1.96, 2.99]
Şeker & Kartal (2017)	11.65	3.18	23	10.39	2.62	23	5.7%	0.43 [-0.16, 1.01]
Winkelmann et al. (2019)	7	1	138	6.9	1	141	6.5%	0.10 [-0.14, 0.33]
Subtotal (95% CI)			**249**			**249**	**24.0%**	**0.79 [-0.24, 1.81]**
Heterogeneity: Tau² = 1.04; Chi² = 69.21, df = 3 (P < 0.00001); I² = 96%								
Test for overall effect: Z = 1.51 (P = 0.13)								
5.3.4 Not reported								
Ahmad et al. (2021)	16.42	2.45	31	14.94	2.7	31	5.9%	0.57 [0.06, 1.08]
Aldosari et al. (2022)	11.23	2.1	26	8.03	2.75	30	5.7%	1.28 [0.70, 1.86]
Hodges et al. (2018)	8.67	3.18	184	6.5	2.18	167	6.5%	0.79 [0.57, 1.00]
Mihindo et al. (2017)	0.69	0.15	43	0.51	0.17	43	6.0%	1.11 [0.66, 1.57]
Nuić & Glažar (2019)	9.9	2.39	39	9.4	2.89	48	6.1%	0.19 [-0.24, 0.61]
Ratamun & Osman (2018)	4.26	0.66	76	4.13	0.65	71	6.3%	0.20 [-0.13, 0.52]
Suleman et al. (2017)	88.29	3.38	25	72.36	3.49	25	4.2%	4.56 [3.48, 5.65]
Subtotal (95% CI)			**424**			**415**	**40.8%**	**1.07 [0.52, 1.62]**
Heterogeneity: Tau² = 0.47; Chi² = 71.49, df = 6 (P < 0.00001); I² = 92%								
Test for overall effect: Z = 3.82 (P = 0.0001)								
Total (95% CI)			**916**			**904**	**100.0%**	**0.98 [0.62, 1.35]**
Heterogeneity: Tau² = 0.52; Chi² = 204.33, df = 16 (P < 0.00001); I² = 92%								
Test for overall effect: Z = 5.27 (P < 0.00001)								
Test for subgroup differences: Chi² = 0.44, df = 3 (P = 0.93), I² = 0%								

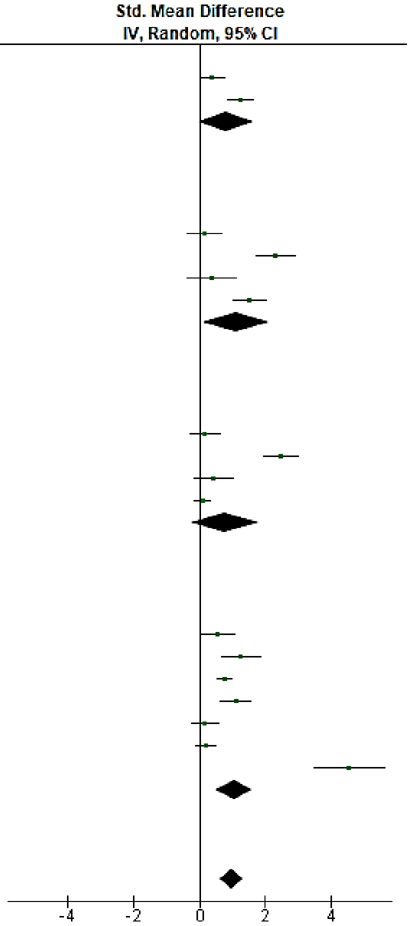

Figure 6. Duration of Implementation

According to Figure 6, the group of studies that failed to report the implementation duration garnered the highest effect size of 1.18. Then, four to six weeks duration has the effect size value of SMD = 1.11, one to three weeks of implementation resulted in an effect size of 0.82, and more than seven weeks of implementation yielded an effect size of SMD = 0.79.

Publication Bias

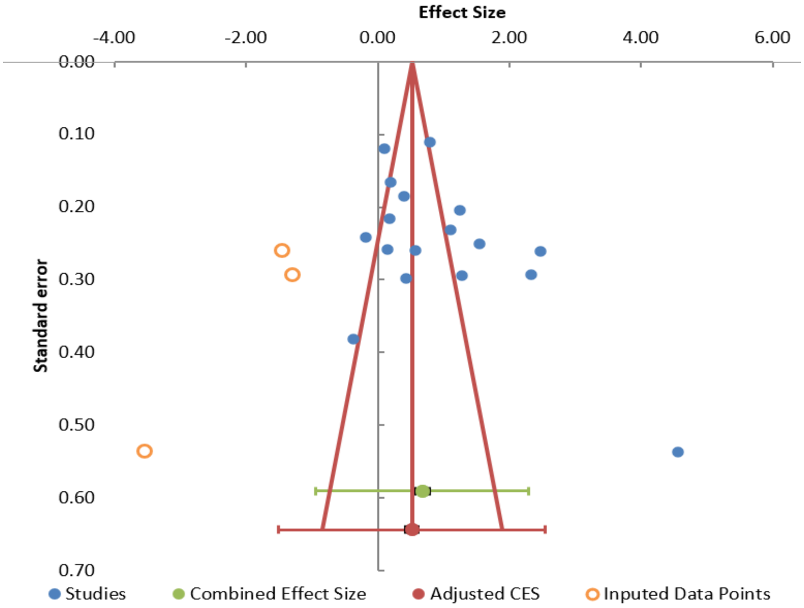

Figure 7. Funnel Plot of Publication Bias Based on Effect Size

The asymmetry in the location of the studies is evident through the initial appearance of the funnel plot. To analyze the publication bias aspect further, Egger's regression test was conducted and obtained (intercept = 4.29; $p > 0.05$). The insignificant result from Egger's regression test implies that the distribution of samples must be symmetric to accept the null hypothesis. In addition, using the Rosenthal fail-safe N test, 1403 studies need to be conducted to ensure that the effect size obtained in the study is insignificant. Also, based on the Orwin fail-safe N test, 214 studies are missing to nullify the results from the study.

The use of virtual laboratories is one of the offshoots of continuously improving technology. A practical way to apply technology in educational settings is through the use of virtual laboratories [39]. Virtual laboratories produce mimicked real-life environments to conduct varied lessons as close to reality as possible [9]. Advantages of virtual laboratories include improved visualization and understanding of the concepts, and learning motivation [23][28]. The virtual laboratories inculcate in the learners the acquisition of skills including communication, collaboration, decision-making, and stress-management [40]. Even though there is already a meta-analysis done about the effect of science laboratories [11], to the best of the researcher's knowledge, there was no study done that focuses on secondary-level Chemistry yet. Also, to deepen the analysis and due to the heterogeneity level of the included studies, sub-group analysis was utilized in this meta-analysis.

After reviewing and analyzing 17 journals that met the inclusion criteria for the study, the meta-analysis discovered the effectiveness of Chemistry virtual laboratories in improving secondary-level learners' academic achievement. The study yielded a total effect size of 0.98 which can be considered a significantly large and positive effect [41]. Therefore, this meta-analysis confirms the array of results yielded by already published studies indicating a positive sign of the use of virtual laboratories in enhancing students' learning achievement [11][25][28].

In addition, the meta-analysis reviews that out of 17 literature, 7 studies resulted in positive and large effect sizes ($g \geq 0.80$). The largest effect size was garnered by the study of [37] where the utilization of Information and Communication Technology (ICT) was done during the learning sessions. One week of training was allotted for the orientation of facilitators and learners in using various computer applications, web browsers, and software. In the findings of [37], it was inferred that use of different types of ICTs such as virtual laboratories significantly improved Chemistry learning.

Furthermore, the studies of [24],[26],[28],[30],[31] and [34] yielded positively large effect sizes. Among these studies, interactive virtual laboratory set-ups were planned and implemented in the studies yielding significantly positive effects. In the study of [24] the innovative combination of simulation and molecular visualization with gesture-based technology was used with the aid of a leap motion controller which can identify rotations and positions of the controller simultaneously to visualize the interactions between atoms, molecules, and bonds. While other interactive settings were utilized by [26] where the augmented reality in the form of the "Elements 4D" application was utilized which is composed of six paper blocks and pointing a block to a side will generate a simulation of the element displayed on the screen.

Moreover, the meta-analysis revealed that two journals rendered a positive medium effect size [23], [27]. Computer-Assisted Instruction was lauded in the study of [23] where animated color and graphics were used to present a dynamic electrolysis process through a multi-sensory approach. On the other hand, Blended Reality Environment (BRE) was constructed and implemented by [27] and combines serious educational games with a hands-on laboratory providing allotment for inquiry, feedback, and performance examination. BRE can blend the macroscopic, microscopic, and symbolic versions of the lesson which enriches the learning in Chemistry.

However, exploring the four studies [25],[33],[35],[36] yielded small effect sizes and three studies [38],[32],[29]resulted in very small effect sizes, traditional teaching methods were employed in the learning process [25]. Although the change in the learning achievement in Chemistry is not significant after the exposure to virtual laboratories, possibly due to factors including budget and time constraints, the improvement in the attitude of learners was observed in the learners [35]. Also, learners got high scores in quizzes and lab reports and commended the Second Life virtual laboratory intervention due to the few distractions, high efficiency, and practical usability [38]. The use of virtual laboratories in the form of PhET Interactive Simulation implies that virtual simulations are as effective as real-life laboratories and can be used instead of traditional laboratories [29].

Analyzing individual journals revealed that most of the studies applied a constructivist approach for the enrichment of the learning process during the interventions with virtual laboratories. Constructivist approaches treat learners as active creators of meanings from the learning process. In the case of [26] peer collaboration was embedded in the learning intervention where students work as a team and acquire an opportunity to discuss results with their peers. Scaffolding and metacognitive strategies were combined with multi-sensory approaches in developing the motivation of learners to continue in learning process [23]. According to sub-groupings, the region of the intervention, the grade level, duration of implementation, and topic in Chemistry was also analyzed in this study yielding the highest effect sizes in Asia, Junior High School Level, unreported duration of implementation, and General Chemistry as the topic involved. Still, learners benefited from the virtual laboratories in Chemistry in any setting may it be the academic achievement and or their motivation towards learning Chemistry.

Additionally, according to the study by [43] [44], incorporating virtual laboratories into chemistry lessons can enhance students' motivation and interest [42], specifically in a branch of organic chemistry that students perceive as complex. Due to the interactivity of virtual laboratories, learners may create concrete ideas, manipulate variables, and analyze results, which will aid the content retention of students. Moreover, virtual laboratories deal with the inequalities in the availability of learning resources. Most secondary-level schools lack enough chemistry laboratories due to limited funding [45]. As a solution, without the requirement for costly equipment, virtual laboratories can be a practical alternative that gives learners the necessary learning experiences.

Implementing virtual laboratories in secondary-level chemistry education requires careful development of existing educational policies [46]. Therefore, stakeholders and policymakers must prioritize sufficient funding and support for embedding virtual learning environments in classes. The instructors who lead the learners must be knowledgeable about implementing activities through virtual laboratories. The provision of professional development to train instructors on integrating virtual laboratories into their lesson plans should be included in the educational policies, as well as the addition of curricular standards with the integration of virtual laboratory experiences.

Designing activities that will provide practical skills acquisition may help the learners understand the topics in chemistry [47]. For example, the lesson about how temperature affects reaction time may induce more concrete visualization of the particles with the help of virtual simulations. Also, fostering collaborative virtual laboratory set-ups will let the learners exchange ideas and modify their existing conceptions to improve the learning process. In addition, real-time assessment and feedback help the learners monitor their progress in exploring virtual laboratory activities. Using reflective logs to record observations from the vitual simulations will strengthen learners' metacognition and improve academic achievement in chemistry [48]-[50].

4. CONCLUSION

The meta-analysis of the effectiveness of virtual laboratories in enhancing secondary learners' achievement in chemistry resulted in an overall effect size of SMD value of 0.98. The findings of this study conclude that employing virtual laboratories in teaching chemistry has a significant positive effect on the learners' achievement in chemistry. As expected, the significant positive effect of virtual laboratories in chemistry is in line with the previously conducted meta-analyses about the effects of virtual laboratories on academic achievement relevant to science subjects.

According to the sub-groupings, the effect of virtual laboratory in teaching chemistry has the largest effect size in Asia, Junior High School level, in General Chemistry. The virtual laboratories used were mostly incorporated with a constructivist approach in teaching which yielded significant positive effects on students' learning achievement in chemistry. The study is limited to the published research in 2017-2022 to reflect on the current state of literature about the effectiveness of virtual laboratories in improving learners' academic achievement. Also, academic achievement was the sole observed variable excluding the attitudes, motivation, and other skills in learning chemistry at the secondary level only excluding tertiary and primary levels of education.

Due to the high level of impact of virtual laboratories in learning chemistry, the learning of the students will be increased and engagement in the learning process will be enhanced compared to the absence of virtual laboratories. The educational sector may consider the positive effects as implied by the results gathered in this meta-analysis, in choosing and procurement process of the instructional materials utilized in learning processes at any educational level, including secondary level. To the educators facilitating chemistry classes, the inclusion of interactive activities while utilizing virtual laboratories is deemed useful in the assurance of success in learners' academic achievement. A constructivist approach may be integrated by the facilitators to alleviate the inquiry, exposure, and collaboration of learners. Also, the parents may support their children by providing devices capable of executing virtual laboratories and may guide their children in navigating devices and monitor their device usage to ensure academic activities are done. Learners should be open-minded and follow the prescribed guidelines given by the instructor in using innovative yet interactive approaches including virtual laboratories in learning subjects including chemistry. Researchers may ponder more about the effectiveness of virtual simulation in different subjects and in improving scientific skills aside from academic achievement.

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