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An Examination of the Studies Between 2013-2022 on the Use of Virtual Laboratories in Science Education*

Sanal Laboratuvarların Fen Eğitiminde Kullanımıyla İlgili 2013-2022 Yılları Arasındaki Çalışmaların İncelenmesi

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ABSTRACT

This study is a systematic review that is composed of the analysis of several international studies on the use of virtual laboratories in science education that were selected based on certain criteria. Research data have been attained by reviewing studies that concern virtual laboratories. For this systematic review, 1322 scientific articles published in the Web of Science database between 2013 and 2022, with the keyword "virtual laboratory" in their titles or abstracts, were reviewed. An article review form was used as the tool for collecting data. In determining the papers to be included in the study, the criterion sampling method was used. The sample of the study consists of 30 papers which comply with the inclusion criteria and were accessible in full text. Descriptive and content analyses were used in this systematic review. The studies on virtual laboratories are presented via descriptive analysis on the basis of their distribution by years, distribution by subject fields, distribution by participant levels, distribution by group sizes, methods and patterns, data collection tools, and frequencies of data analysis types. The results of virtual laboratories that these studies acquired were grouped via content analysis under codes, categories, and themes. When the results achieved by these studies are evaluated as a whole, it becomes clear that virtual laboratory applications positively impact science education with respect to different variables.

Keywords: *Virtual laboratory, Science education, Systematic review.*

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ÖZ

Bu araştırma; sanal laboratuvarların fen bilimleri eğitiminde kullanılmasıyla ilgili yapılmış uluslararası çalışmaların belli ölçütler çerçevesinde seçilip analiz edilmesinden oluşan bir sistematik derlemedir. Araştırma verileri, sanal laboratuvara yönelik araştırmaların incelenmesiyle elde edilmiştir. Sistematik derleme olan bu araştırmada 2013-2022 yılları arasında Web of Science veri tabanında başlık ve özet kısımlarında sanal laboratuvar anahtar kelimesinin geçtiği 1322 makale incelenmiştir. Veri toplama aracı olarak araştırmacılar tarafından geliştirilen makale inceleme formu kullanılmıştır. Çalışmaya dahil edilecek makalelerin belirlenmesinde ölçüt örneklem yöntemi kullanılmıştır. Dahil edilme kriterlerine uyan ve tam metnine ulaşılabilen 30 makale çalışmanın örneklemini oluşturmuştur. Veriler analiz edilirken araştırmacılar arası tutarlılığa dikkat edilmiş ve kodlayıcılar arası güvenirlik %90 hesaplanmıştır. Bu sistematik derleme kapsamında verilerin analizinde betimsel analiz ve içerik analiz kullanılmıştır. Betimsel analizde sanal laboratuvarla ilgili yapılan çalışmaların; yıllara göre dağılımı, konu alanlarına göre dağılımı, katılımcı düzeylerine göre dağılımı, grup büyüklüklerine göre dağılımı, yöntem ve desenleri, veri toplama araçları ve veri analiz biçimlerinin frekansları sunulmuştur. İçerik analizinde ise çalışmaların sanal laboratuvarla ilgili ulaştıkları sonuçlar kod, kategori ve temalar oluşturacak şekilde gruplandırılmıştır. Araştırma sonuçları genel olarak değerlendirildiğinde, sanal laboratuvar uygulamalarının fen eğitimini farklı değişkenler bakımından olumlu etkilediği görülmüştür.

Anahtar Sözcükler: *Sanal laboratuvar, Fen bilimleri eğitimi, Sistematik derleme.*

INTRODUCTION

In today's world, science and technology are improving day by day. These improvements have made it almost inevitable to use information and communication technologies in education. These technologies take the form of virtual learning systems, virtual classes, and virtual laboratories in educational processes. Virtual laboratories can be deemed to have a significant impact on especially science education when the goals in this area are considered (Ahmed & Hasegawa, 2019). Science classes have essential goals such as teaching students of different ages the scientific information processes and improving their skills of researching this scientific information and problem-solving (Klentien & Wannasawade, 2016). Laboratories are very important in achieving the goals of science lessons (Špernjak & Šorgo, 2018).

Science laboratories are classrooms that are tailored for the goals of science classes, which include scientific practices like displays and experiments (Çepni & Ayvacı, 2019).

These laboratories have many goals, including enabling students to learn about concepts, understand scientific methods, and improve their problem solving, analytical, and psychomotor skills. Laboratories are the cornerstones of science at every stage. They motivate students and raise their interest in science by providing them with an opportunity to think critically like a scientist. Since laboratory activities are generally carried out in groups, laboratories may, at times, serve to improve communication skills and peer learning, as well (Achuthan, Francis and Diwakar,2017; Barrie, Bucat, Buntine, Burke da Silva, Crisp, George, Jamie, Kable, Lim, Pyke, Read, Sharma & Yeung, 2015; Coştu, Ayas, Çalık, Ünal & Karataş, 2005; Lee, Lai, Alex Yu, & Lin, 2012; Pun & Tai,2021).

On the other hand, reasons such as lack of budget and equipment, and some students being active whereas others being passive in experimental groups may result in inequality in learning (Achuthan, Francis and Diwakar, 2017). Virtual laboratories step in at this point as a prerequisite or alternative to physical laboratories. Moreover, virtual laboratories provide students with the chance to move freely from one point to another and conduct experiments repeatedly (Ali, Ullah & Khan, 2022). Virtual laboratories are early simulation extensions of electronic systems that simulate physical laboratories and aim to achieve similar goals. They provide much convenience in visualizing, problem solving, designing an experiment, and commenting on the gathered data (AlZahrani, 2015; Koç Ünal & Şeker, 2020). It can also be stated that they are a necessity thanks to the fun and understandable learning environment they offer and due to the unlimitedness of the user and the period enabled by distant teaching practices (Ayas & Tatlı, 2011).

Taking student and teacher experiences into account, virtual laboratories are regarded as an important part of learning in new education trends. Students have the chance to try something repeatedly through these laboratories (Deepika, Bala & Kumar, 2021). Virtual laboratories create an alternative to traditional learning environments where students can test their scientific hypotheses, interact with each other, and make scientific inquiries. Virtual laboratory environments are stated in many studies to play an important role in increasing students' performances and enabling permanent learning. They may improve students' higher-order thinking, scientific thinking, and scientific inquiring skills

(Puntambekar, Gnesdilow, Dornfeld Tissenbaum, Narayanan & Rebello, 2021; Topalsan, 2020).

Nevertheless, there are some researchers who underline that there are several negative aspects of virtual laboratories as well as positive ones. For instance, Karlsson, Ivarsson and Lindström (2013) state that the integration of virtual laboratories into education is a new development, that it may be the impact of this novelty that leads students to attend the lessons actively and that virtual laboratories should be used on a more regular basis at schools before reaching a solid explanation.

Winkelmann, Scott & Wong (2014) argue that virtual laboratories cannot provide the student with all of the learning experiences physical laboratories offer. They exemplify this with students not being able to use physical equipment and real chemicals in virtual laboratories. They additionally emphasize that the safety of virtual laboratories does not guarantee that students will accordingly work safely and conscientiously in the real world. Despite all these, Gunawan, Harjono, Sahidu & Herayanti (2017), indicate, referring to the definitions in the literature, that virtual laboratories are not rivals to physical laboratories and they should be deemed as extensions to new opportunities in experiments that cannot be carried out in real life due to the lack of suitable conditions. Virtual laboratories prove to be useful in continuing science education, especially under unexpected circumstances such as epidemics, disasters, wars, and so on since they are independent of time and space.

There are several studies that follow systematic review processes concerning virtual laboratories (Chan, Van Gerven, Dubois & Bernaerts, 2021; Reeves & Crippen, 2021; Triejunita, Putri & Rosmansyah, 2021; Zhang, Al-Mekhled & Choate, 2021). The present study is a systematic review which differs from other studies with respect to the studies that were reviewed within and the inclusion-exclusion criteria that were used. In the research process, the scientific articles that were published in the Web of Science database between 2013 and 2022 were browsed, analyzed, and gathered under certain categories to present the general trends in these studies and analyze the results they achieved. The present researchers reckon that the findings in this research will prove to be guiding in detecting the gaps in the literature and research trends.

This research aims to review international studies between 2013-2022 about virtual laboratories in science education in a systematic fashion. To that end, the questions and subquestions below were aimed to be answered.

RQ1-What are the general trends in studies on virtual laboratories?

RQ1.1- What are the distribution of the studies by years on virtual laboratories?

RQ1.2- What are the distribution of the studies by subject fields?

RQ1.3- What are the distribution of the studies by participant levels?

RQ1.4-What are the distribution of the studies by sample sizes?

RQ1.5- What are the methodological trends of the studies?

RQ2-What are the results achieved in these on about virtual laboratories?

METHOD

This study is a systematic review composed of the analysis of some of the present studies that were selected based on certain criteria. According to Higgins and Green (2011), systematic review is a synthesis of publications related to the research question compiled based on predetermined criteria. The goal here is to review relevant academic publications with a systematic method to reduce the error rate before making inferences or reaching a conclusion based on earlier research on a subject.

Data Source

In this study, the criterion sampling method, with criteria that were determined by the researchers or predetermined criteria, was used (Yıldırım & Şimşek, 2018).

Research data have been acquired by examining studies on virtual laboratories in August and March, 2022. Studies which complied with the inclusion criteria and were accessible in full text were included in the scope of the review. The selection process is presented in detail and in order along with inclusion and exclusion criteria in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	**The Number of the Studies Accessed**	**Exclusion Criteria**
Studies in the Web of Science database that have the keyword "virtual laboratory" in their titles or abstracts were selected.	1322	Studies that were not in the Web of Science database were excluded.
Studies on education and educational sciences were selected.	516	Areas like engineering and applied sciences were excluded.
English was selected as the language.	495	Studies that were not published in English were excluded.
SCI-Expanded, SSCI and ESCI indexes were selected.	234	Studies that were not in the SCI-Expanded, SSCI and ESCI indexes were excluded.
Studies between 2013-2022 (the last decade) were selected.	150	Studies that were not published between 2013-2022 (the last decade) were excluded.
Scientific articles and early access were selected as the document type.	143	Publication types like book chapters and proceedings were excluded.
Studies on science education, physics education, chemistry education and biology education were selected.	38	Studies on engineering and applied sciences education were excluded.
Studies that were conducted with K-12 students, teachers and teacher candidates were selected.	**30**	Studies that were conducted with undergraduate students in departments other than educational sciences and graduate groups were excluded.

In this study, the authors first accessed "1322" studies in the Web of Science database which have the phrase "Virtual Laboratory" in their titles or abstracts. Then, 150 studies on education and educational sciences which were published between 2013-2022 in English and find place in the SCI-Expanded, SSCI and ESCI indexes were selected in accordance with the inclusion criteria. The number was reduced to 143 studies by filtering those through selecting scientific articles and early access as the document type. Thirty-eight studies on science, physics, chemistry and biology education were selected from among these. In the last step, 30 studies carried out with K-12 students, teachers and teacher candidates were included in this systematic review.

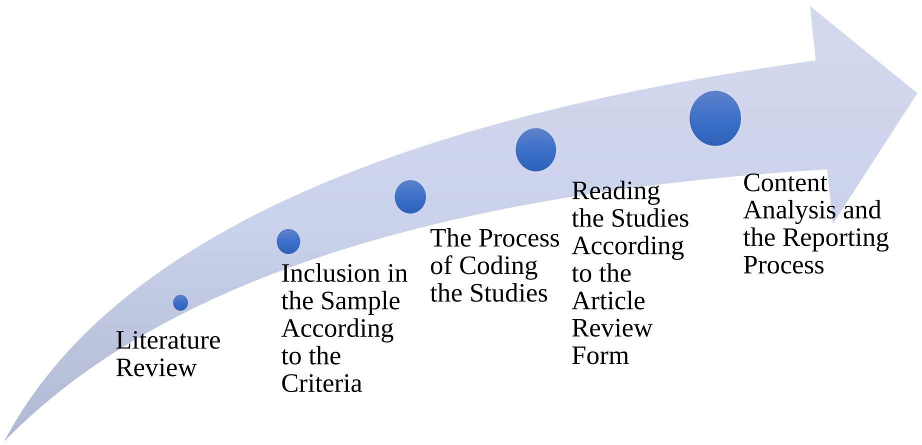
Data Collection Tool

In this study, an article review form that was designed by the researchers was used. This form is a table that consists of three sections. The first section includes references of the studies, the second section includes the methodological information concerning the studies, and the third section includes information on the results of the studies (Appendix B).

Implementation Process

Figure 1presents all the stages of the systematic review that is carried out for this study in order.

Figure 1. The Stages of the Research Process



In the beginning, the 30 studies that remained after applying the inclusion and exclusion criteria were named according to the authors' surnames and publication dates, and then listed in alphabetical order. In line with this ordering, the studies were coded as A1, A2, A3… A30. The coded studies were read in order according to the paper review form, and then, relevant information and results were written on the form. After all the studies had been read, descriptive analysis, content analysis and reporting processes were carried out.

Data Analysis

In this systematic review, descriptive analysis and content analyses were used. The studies on virtual laboratories are presented in tables via descriptive analysis on the basis of their distribution by years, distribution by subject fields, distribution by participant levels, distribution by group sizes, methods and patterns, data collection tools, and frequencies of data analysis types. The results about virtual laboratories that these studies acquired were grouped via content analysis in a way that would form codes, categories, and themes.

The collected data were then reviewed by the two present researchers independently. Firstly, the researchers reached a consensus on how to conduct the analysis process. Then, they coded approximately 20% of the data independently and compared their coded parts. Common points and conflicting points were detected, after which the researchers continued coding the data and calculated the intercoder reliability, respectively. According to the calculation, the reliability coefficient was 90% (Miles and Huberman, 2015, pp. 64-65).

FINDINGS

This study aims to systematically analyze international studies that were published between 2013-2022 about virtual laboratories in science education. Towards that aim, the findings regarding the research questions are presented below:

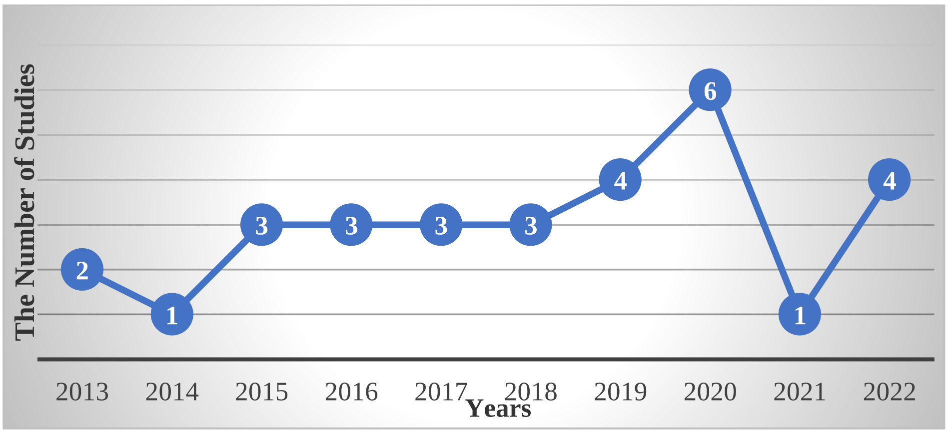
RQ1*:* What are the general trends in studies on virtual laboratories?

To find an answer to the first research question, the distribution by years, distribution by subject fields, distribution by participant levels, distribution by group sizes, methods and patterns, data collection tools, and frequencies of data analysis types of the studies on virtual laboratories were identified.

RQ1.1: What are the distribution of the studies by years on virtual laboratories?

The distribution of the studies that were examined in this research by years is shown in Figure 2.

Figure 2. RQ1.1. The Distribution of the Studies by Years

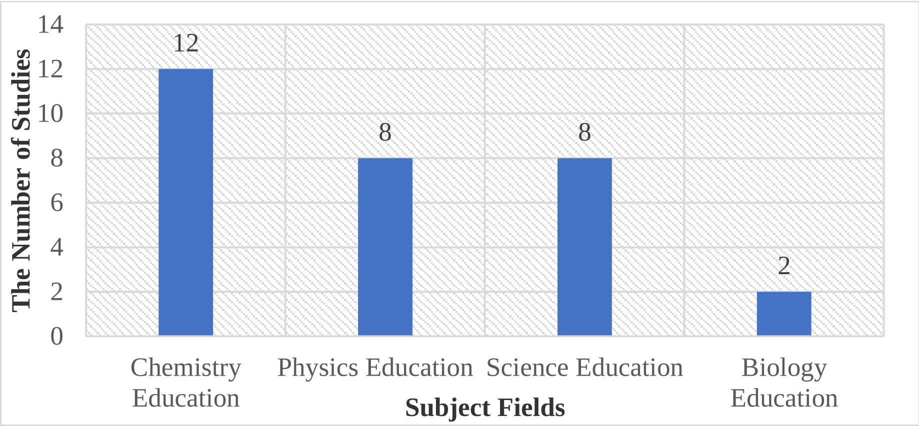


When Figure 2 is examined, it can be stated that the number of studies on virtual laboratories have increased especially from 2019, when the COVID-19 pandemic started, on. Moreover, it is seen that half of the examined studies have been carried out in the last 4 years.

RQ1.2: What are the distribution of the studies by subject fields?

The distribution of the studies that were examined in this research by subject fields is shown in Figure 3.

Figure 3. RQ1.2 The Distribution of The Studies by Subject Fields

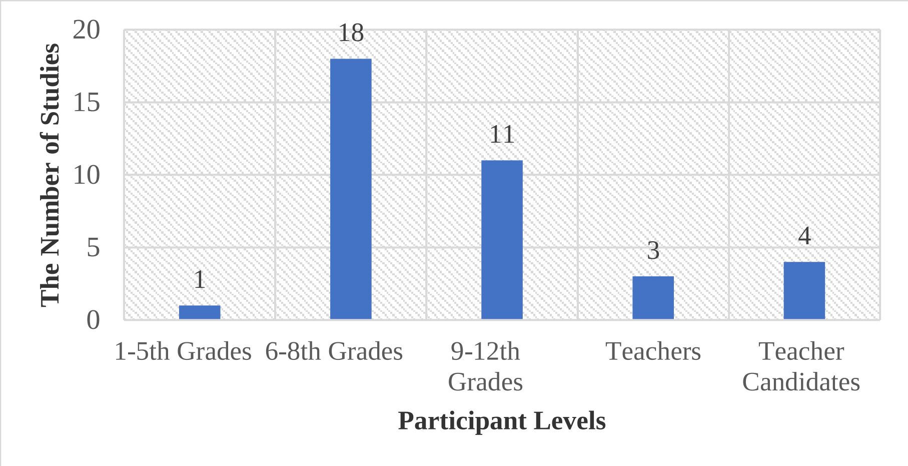


When Figure 3 is examined, it is seen that most studies on virtual laboratories are in the field of chemistry education (f=12), and that the studies on physics education (f=8) and science education (f=8) are relatively less in number compared to chemistry education. Additionally, it is worth noticing that the number of studies on biology education (f=2) are quite few compared to the other fields.

RQ1.3: What are the distribution of the studies by participant levels?

The distribution of the studies that were examined in this research by participant levels is shown in Figure 4.

Figure 4. RQ1.3 The Distribution of the Studies by Participant Levels

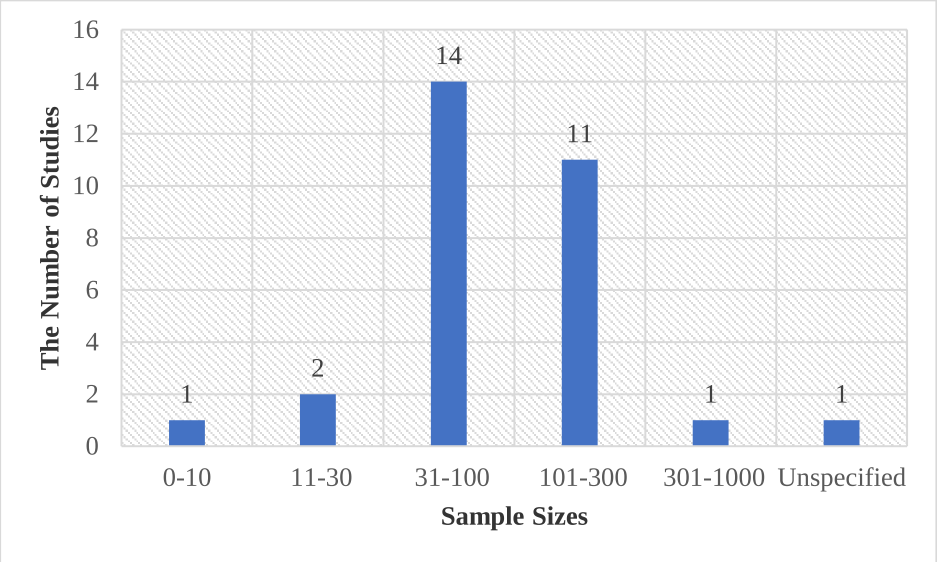


When Figure 4 is examined, it is noticed that most studies on virtual laboratories were carried out with 6-8th graders (f=18) and 9-12th graders (f=11), and that the studies carried out with 1-5th graders (f=1), teachers (f=3) and teacher candidates (f=4) are less in number. Notice that the sum of the numbers in Figure 4 is more than the number of studies examined. This may be caused by the fact that some studies used more than one sample group.

RQ1.4: What are the distribution of the studies by sample sizes?

The distribution of the studies that were examined in this research by group sizes is shown in Figure 5

Figure 5. RQ1.4 The Distribution of the Studies by Sample Sizes



When Figure 5 is examined, it can be seen that most studies were conducted with groups involving 31-100 people, which is followed by groups with 101-300 people. It can be stated that studies with groups with 0-30 people and more than 301 people are relatively few.

RQ1.5: What are the methodological trends of the studies?

The findings presented in Table 2 show the methodological trends of the studies.

Table 2. Methodological Trends of the Studies

Methods and Patterns of the Studies	**f**
Quantitative Studies	**19**
Studies with Quasi-Experimental Pattern	15
Other Experimental Patterns	2
Comparative Analysis	1
Quantity Based Evaluation Research	1
Qualitative Studies	**2**
Basic Qualitative Research	1
Ethnomethodology	1

Studies with a Mixed Method Design	**3**
Sequential Mixed Method for Quasi-Experimental Design	1
Exploratory Design	1
Mixed Methods Involving Integration	1
Not Identified Clearly	**6**
Data Collection Tools	**f**
Quantitative Data Collection Tools	
Knowledge and Success Tests	14
Satisfaction Questionnaires	8
Measurement Tools That Measure Skills	8
Tests Intended at Assessing Laboratories	6
Tests that Measure Conceptional Understanding	4
Attitude Scales	3
Measurement Tools Based on Experimenting Performance	3
Qualitative Data Collection Tools	
Interview Forms	8
Observation Forms	5
Student Documents	3
Other Questionnaires	3
Other Measurement Tools	3
Data Analysis Types	**f**
Quantitative Data Analyses	
Descriptive Analysis	**15**
Predictive Analysis	
T Test	14
ANOVA/ANCOVA	15
MANOVA/MANCOVA	2
Chi Square	4
Factor Analysis	3
Wilcoxon Signed Ranks Test	2
Mann Whitney U Test	1
Kruskal-Wallis Test	1
Rasch Modeling Technique	1
Qualitative Data Analyses	
Content Analysis	6
Reliability Analyses	

Quantitative Reliability Analyses	
Cronbach Alpha	8
Cohen's Kappa	3
Kudar Richardson (KR-21)	1
KR-20 Reliability Coefficient	1
Qualitative Reliability Analyses	
Intercoder Reliability	5

According to Table 2, the studies generally have a quantitative pattern and quasi-experimental design. On the other hand, it is a remarkable finding that the number of studies with a qualitative or mixed method is few. Moreover, it is noticed that 6 of the examined studies do not clearly specify a research pattern. Data collection tools and data analysis types that were used in the studies were affected by research designs, as well. Regarding this, it is observed that data collection tools used in quantitative studies and quantitative data analysis types outnumber others. In addition, reliability analyses are shaped by quantitative analyses.

***RQ2*- What are the results achieved in these studies on virtual laboratories?**

The present researchers have examined the results of the studies that were included in the research with respect to the second research question by content analysis. At the end of this examination, each result achieved by these studies was coded one by one. After coding, categories and subcategories were determined, followed by themes. As is shown in Table 3, the results of the studies were categorized under two main themes as positive and negative. Under the theme of positive results, five categories find place. These are results concerning the use of virtual laboratories, laboratory processes, the affective field, the cognitive field, and skill development. Among these, the results concerning the cognitive field are divided into 3 subcategories, namely results concerning concept teaching, results concerning academic achievement and other cognitive results. Other categories do not have any subcategories.

Table 3. Results Concerning Virtual Laboratories

Themes	Categories	Subcategories	Codes	f	Relevant Studies
Positive Results	**Results Concerning the Use of Virtual Laboratories**	No Subcategory	Being applicable for science education	8	A2, A3, A5, A6, A17, A19, A27, A28
			Offering an independent learning environment	1	A3
			Being functional	1	A5
			Interface satisfaction	1	A5
			Having the advantage of visualization	1	A5
			Being handy and practical	1	A5
			Being accessible	1	A6
			The necessity to be adapted to other courses	1	A5
			Offering an effective user experience	1	A19
			Being helpful in limited conditions	1	A23
			Offering a critical and scientific course content	1	A25
			Creating a positive educational atmosphere	1	A25
			Being advantageous in terms of time	1	A28
	Results Concerning	No Subcategory	Being advantageous in terms of being used along with a physical laboratory	3	A22, A27, A28
			Enhancing the experimenting performance	2	A1, A26

Laboratory Processes		Increasing self-efficacy regarding the laboratory	1	A13
		Increasing participation in the physical laboratory	1	A13
		A similar experience to physical laboratories	1	A13
		Introducing laboratory equipment	1	A24
Results Concerning the Affective Field	No Subcategory	Raising interest	5	A13, A17, A19, A25, A28
		Being fun	4	A11, A17, A25, A28
		Improving attitude	2	A17, A20
		Increasing motivation	2	A13, A25
		Having a high level of emotional participation	1	A13
Results Concerning the Cognitive Field	**Results Concerning Concept Teaching**	Improving conceptional understanding	6	A3, A8, A9, A19, A20, A27
		Being effective in concept teaching	2	A11, A23
		Improving conceptional explanation	1	A4
		Explaining the relationship between concepts	1	A18
	Results Concerning Academic Achievement	Increasing the level of success	7	A6, A11 A13, A19, A24, A29, A30
		Being advantageous in terms of structuring knowledge	6	A8, A9, A16, A19, A22, A27

			The impact on self-directed and autonomous learning	1	A20
			Facilitating learning	1	A20
			Improving the ability to remember information	1	A29
		Other Cognitive Results	Reducing the cognitive burden	1	A1
			Improving the formation of mental models	1	A8
			Reaching high-level cognitive goals	1	A9
			Improving the competence of modeling data	1	A10
			Developing the relationship between scientific ideas	1	A21
	Results Concerning Skill Development	No Subcategory	Enhancing inquiry skills	6	A12, A14, A15, A16, A20, A25
			Enhancing creativity	1	A7
			Improving problem solving skills	1	A29
			Developing metacognitive skills	1	A30
			Enhancing the skills in writing arguments and providing evidence	1	A15
Negative Results	**No Category**	No Subcategory	Low flexibility	1	A6
			Being costly to develop	1	A6
			Having a low experimenting performance	1	A11
			Little impact on the development of scientific process skills	1	A20

	Not being preferred by students	1	A20
	Being boring	1	A22
	Low levels of motivation	1	A22

When the categories are examined in general, an important finding arises: the "being applicable for science education" code in the "results concerning the use of virtual laboratories" category has more studies compared to other codes.

In the examined studies, the results that virtual laboratories are advantageous to be used along with physical laboratories and that virtual laboratories enhance the experimenting performance are prominent in the category of "results concerning the laboratory processes". Moreover, results that endorse that virtual laboratory increase self-efficacy in laboratories and participation in physical laboratories, offer experiences similar to those of physical laboratories and introduce laboratory equipment have been achieved.

In the category of "results concerning the affective field", codes like virtual laboratories being interesting and fun, and improving attitude and motivation have emerged.

It can be seen that the category of "results concerning the cognitive field" has 3 subcategories: results concerning concept teaching, results concerning academic achievement, and other cognitive results. It should be underlined that the results concerning the cognitive field have subcategories and more codes compared to the other categories. This fact points towards the possibility of studies using virtual laboratories in science teaching focusing more on cognitive fields.

When the category of "results concerning skill development as a consequence of using virtual laboratories in science education" is examined, it is observed that the results indicating virtual laboratories improve especially inquiry skills are more than results about other skills. Additionally, there are results indicating that virtual laboratories enhance creativity, problem solving skills and writing arguments and providing evidence skills.

It can be realized that negative results about virtual laboratories have a significantly lower frequency than positive results. Notice that Table 3 includes no categories or subcategories under the theme of negative results. However, results such as low flexibility, being costly to develop, low experimenting performance, little impact on the development of scientific process skills, not being preferred by students, being boring, and low levels of motivation are present for virtual laboratories in the codes relating to negative results.

CONCLUSION & DISCUSSION

This study aims to analyze international studies between 2013-2022 on the use of virtual laboratories in science education systematically. To that end, 30 studies were examined in terms of their general trends and results. With respect to the general trends of these studies, their distribution by years, distribution by subject fields, distribution by participant levels, distribution by group sizes, methods and patterns, data collection tools, and frequencies of data analysis types were examined. Taking the results of the systematic review into account, studies on virtual laboratories can be stated to trend towards an increase in recent years. It is assumed that the interest in virtual laboratories has been on the increase especially in the wake of Covid 19. It is reckoned that virtual laboratories will find themselves a larger space in the attitude toward science education in different countries as a consequence of the developments in science and technology. Regarding the examined studies, it is worth remarking that biology-education-related studies are considerably fewer than other fields. When the participant levels are taken into consideration, only one study is conducted with 1-5th graders. This situation may be related to the fact that science laboratories do not find a large area of use in early grades. Nevertheless, the present researchers reckon that laboratories should be popularized in science education in early grades, and virtual laboratories should play more role in science education as a result of technologization in education. It can be stated that virtual laboratories may make the students in early grades enjoy science classes and laboratories due to especially the results listed under the category of “results concerning the affective field” such as virtual laboratories being fun and interesting, and improving the attitude and motivation. Observing the examination of the studies on the basis of participant levels, another important point is that the studies conducted with teachers and teacher candidates are few. It can be remarked that more studies on virtual laboratories should be conducted with teachers and teacher candidates considering that they are the ones to educate students. When the methodological trends of the studies are examined, it is noticed that approximately 2/3 of them have a quantitative pattern and quasi-experimental design, and, accordingly, data collection tools, data analysis types and reliability analyses are shaped around quantitative paradigms. Studies in which quantitative methods overweigh provide a chance to compare virtual laboratories with other environments or beginning stages. On the other hand, studies conducted with a qualitative or mixed method are few. This shows that deeper research on the use of virtual laboratories in science education is needed.

The results of the studies on virtual laboratories are gathered under two themes as positive and negative. It is observed that the studies have generally positive results about virtual laboratories.

Eight of the studies that were examined within the scope of this research (Almazaydeh, Younes & Elleithy, 2016; Arista & Kuswanto,2018; Daineko, Ipalakova, Tsoy, Bolatov, Baurzhan & Yelgondy, 2020; Falode, & Gambari, 2017; Kapici, Akcay, & de Jong, 2020; Lai, Lin, Chou, & Yueh, 2022; Wang & Tseng, 2018; Winkelmann, Scott & Wong, 2014) have achieved the result that virtual laboratories are utilizable in science education. Although this is a significant result, it is not surprising at all. In the examined studies, it was a common practice to compare virtual laboratories with physical laboratories, whereas virtual laboratories are offered as alternatives in some studies and seen as supplementary elements in others (Chen,2010; Koç, Ünal & Şeker,2020; Tüysüz, 2010). Other codes in the same category indicate that the use of virtual laboratories bring different positive consequences with them.

Based on the category of "results concerning laboratory processes", it can be said that the use of virtual laboratories may prove to be highly advantageous (Špernjak & Šorgo 2018; Wang &Tseng, 2018; Winkelmann, Scott & Wong, 2014). When the examined studies are taken into account, it can also be said that virtual laboratories will have a positive impact on experimenting performances (Ali, Ullah & Khan, 2022; Ullah, Ali & Rahman, 2016). Students may have a general idea of how experiments are carried out via the experiments carried out in virtual laboratories. This opportunity may increase the feeling of "achievement" and enhance the performance in physical laboratories. When used efficiently, virtual laboratories can be predicted to have positive impacts like increasing the participation in physical laboratories, offering a similar experience to that of physical laboratories, introducing the equipment and increasing the self-efficacy in laboratories, which are the other results in the mentioned category.

Different results like being interesting and fun and improving the attitude and motivation emerge for virtual laboratories in the category of "results concerning the affective field" (Jagodziński & Wolski, 2015; Kapici, Akcay, & de Jong, 2020; Lai, Lin, Chou, & Yueh, 2022; Topalsan, 2020; Winkelmann, Scott, & Wong, 2014; Husnaini, & Chen, 2019; Penn, & Mavuru, 2020). One of the significant points that is underlined often in the literature is that these results may be rooted in the novelty of virtual laboratories rather than their content. A novel phenomenon or an education technology can indeed be interesting for students. Yet, following the systematic review, we suppose that the many positive results in the affective field are not only related to novelty, and content, too, is appealing for students in terms of affection.

Looking at the results concerning the cognitive field, we can point out important cognitive results like virtual laboratories being generally effective in concept teaching, enhancing academic achievement and facilitating structuring knowledge. Additionally, it can be underlined that they help remember information, facilitate learning, and have a positive impact on self-directed, autonomous learning. It is seen that nearly 2/3 of the studies examined in the systematic review are about cognitive processes. The fewness of the studies on the results under the "other results" category, namely the cognitive burden, forming a mental model, high-level cognitive goals, data modeling competency and development of the relationship between scientific ideas, point towards the need for more research in these contexts (Ali, Ullah & Khan, 2022; Arista, & Kuswanto, 2018; Chiu, DeJaegher & Chao, 2015; Falode & Gambari, 2017; Herga, Čagran & Dinevski, 2016;

Herga, Glažar & Dinevski, 2015; Hung & Tsai, 2020; Husnaini & Chen, 2019; Jagodziński & Wolski, 2015; Kapici, Akcay & de Jong, 2019; Karlsson, Ivarsson & Lindström, 2013; Lai, Lin, Chou & Yueh, 2022; Penn & Mavuru, 2020; Puntambekar, Gnesdilow, Dornfeld Tissenbaum, Narayanan & Rebello, 2021; Špernjak & Šorgo 2018; Sullivan, Gnesdilow, Puntambekar & Kim, 2017; Tatli & Ayas 2013; Wang & Tseng, 2018; Wolski & Jagodziński, 2019; Yusuf & Widyaningsih, 2020).

The results concerning skill development reveal that studies with this perspective are fewer in number than other categories. Significant findings on virtual laboratories enhancing inquiry skills were achieved in these studies (Ifthinan & Atun, 2019; Kapici, Akcay & Cakir, 2022; Kapici, Akcay & Koca, 2022; Kapici, Akcay, & de Jong, 2019; Penn & Mavuru, 2020; Topalsan, 2020). Nonetheless, studies on other skill types are relatively few. Only one study was accessed for each of the following skills: creativity (Gunawan, Harjono, Sahidu & Herayanti, 2017), problem solving (Wolski & Jagodziński, 2019) and metacognitive skills (Yusuf & Widyaningsih, 2020). It is thought that there is a need for original studies on the effect of virtual laboratory use in science education on skill development, in particular 21st century skills and basic skills.

In this systematic review, it has been discovered that virtual laboratories have negative results as well as positive ones. We think that although the studies including such results are few, they contribute to the literature considerably.

One study achieved the result that virtual laboratories have a low level of flexibility and are costly to develop (Falode & Gambari, 2017). On top of this, there are results in other studies like not being preferred by students, being boring, and causing low levels of motivation (Penn & Mavuru, 2020; Špernjak & Šorgo, 2018). The negative results that are mentioned until this point are about the use of virtual laboratories. It is important that virtual laboratories are interesting and flexible to use, and it is normal to have these negative outcomes if the content is not interesting for the student and inflexible. Researchers can use the existent software as well as develop their own software for virtual laboratory activities. There are things to consider in this case. If the existent virtual laboratory software is suitable for the purposes and achievement goals of the class, it can be used. However, if researchers aim to develop an original virtual laboratory, this should be economical in terms of time and cost. There are other negative results such as low experimenting performance (Husnaini & Chen, 2019) and little impact on scientific process skills (Penn & Mavuru, 2020). These negative results are deemed to be rooted in the "not being there" factor related to virtual laboratories. Students experience a lack of tactile and sensory processes in some virtual laboratory activities.

RECOMMENDATIONS

According to this study, it can be stated that there is a need for different studies on virtual laboratories in the future. The authors reckon that for the future virtual laboratory technologies, technological systems which can increase the feeling of "being there" such as "Natural User Interfaces" should be increased rather than focusing on a desk experience. Afterwards, it is crucial to design virtual laboratories that are used in science education according to the needs and interests of students and to prepare the content according to students' levels. In academic studies, qualitative research that offers a chance to evaluate virtual laboratories in depth can be designed rather than research with a quantitative pattern in which virtual laboratories are compared with physical laboratories in terms of different variables. Conducting studies at primary school levels instead of only secondary school and high school levels can also enrich the field in terms of sample groups. It is thought that virtual laboratories can even be used to render science education accessible for the groups that are described as disadvantageous in education who experience hardships in accessing education, and that this would be a significant step towards ensuring equality in education.

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GENİŞ ÖZET

Amaç: *Bu araştırmanın amacı; 2013-2022 yılları arasında fen bilimleri eğitiminde sanal laboratuvarla ilgili yapılmış uluslararası çalışmaların sistematik olarak analiz edilmesidir. Bu amaç doğrultusunda aşağıda yer alan iki araştırma sorusuna cevap aranmıştır:*

1- *Sanal laboratuvarla ilgili yapılan çalışmaların genel eğilimleri nelerdir?*

2- *Sanal laboratuvarlar ilgili yapılan çalışmalarda ulaşılan sonuçlar nelerdir?*

Yöntem: *Bu araştırma, mevcut çalışmaların belli ölçütler çerçevesinde seçilip analiz edilmesinden oluşan bir sistematik derlemedir. Higgins ve Green'e (2011) göre sistematik derleme, belli bir araştırma sorusuna cevap verebilmek amacıyla, araştırma sorusu ile ilgili yayınların önceden belirlenmiş ölçütler çerçevesinde bir araya getirilerek sentezlenmesidir. Burada amaç, herhangi bir konu ile ilgili daha önce yapılmış araştırmalar üzerinden bir çıkarım yapmadan veya karar vermeden önce, konuya ilişkin akademik yayınları sistematik bir yöntem ile inceleyerek hata oranını azaltmaktır. Bu çalışmada araştırmacılar tarafından oluşturulan veya önceden belirlenen ölçütlerin yer aldığı ölçüt örnekleme yöntemi kullanılmıştır.*

İlk olarak Web of Science veri tabanında başlık ve özet kısmında "Virtual Laboratory" kelimesinin geçtiği "1322" çalışmaya ulaşılmıştır. Ardından eğitim ve eğitim bilimleri alanında yürütülmüş, dili İngilizce olan, SCI-Expanded, SSCI ve ESCI indekslerinde taranan ve 2013-2022 yıllarında yayınlanan 150 çalışma dahil etme kriterleri kapsamında seçilmiştir. Doküman tiplerinden makale ve early access kısımları filtrelenerek 143 çalışma belirlenmiştir. Bu çalışmalardan fen eğitimi, fizik eğitimi, kimya eğitimi ve biyoloji eğitiminde yürütülen 38 araştırma seçilmiştir. Son olarak K-12 sınıf öğrencileri, öğretmenler ve öğretmen adaylarıyla yürütülen 30 araştırma sistematik derlemeye dâhil edilmiştir.

Araştırma verileri, Ağustos 2021 ve Mart 2022 tarihlerinde sanal laboratuvara yönelik araştırmaların incelenmesiyle elde edilmiştir. Araştırma kapsamında dahil edilme kriterlerine uyan ve tam metnine ulaşılabilen araştırmalar çalışmaya dahil edilmiştir. Bu sistematik derleme kapsamında verilerin analizinde betimsel analiz ve içerik analiz kullanılmıştır.

Bulgular: *Birinci araştırma sorusuna yanıt bulmak amacıyla sanal laboratuvarla ilgili yapılan çalışmaların yıllara göre dağılımı, konu alanlarına göre dağılımı, katılımcı düzeylerine göre dağılımı, grup büyüklüklerine göre dağılımı, yöntem ve desenleri, veri toplama araçları ve veri analiz biçimlerinin frekansları belirlenmiştir.*

İkinci araştırma sorusu kapsamında çalışmaya dahil edilen makalelerin sonuçları araştırmacılar tarafından içerik analizi yapılmak üzere incelenmiştir. Bu inceleme neticesinde araştırmaların her birinin ulaştıkları sonuçlar tek tek kodlanmıştır. Kodlama işlemi sonunda kategorilere ve alt kategorilere ulaşılmış ardından temalar belirlenmiştir. Araştırma sonuçları olumlu ve olumsuz sonuçlar olmak üzere iki ana tema altında toplanmıştır.

Tartışma ve Sonuç: *Bu çalışmanın amacı 2013-2022 yılları arasında fen bilimleri eğitiminde sanal laboratuvarla ilgili yapılmış uluslararası çalışmaların sistematik olarak analiz edilmesidir. Bu amaç doğrultusunda 30 çalışmanın genel eğilimleri ve ulaştıkları sonuçlar incelenmiştir.*

Sistematik derleme neticesinde sanal laboratuvarlarla ilgili yapılan çalışmaların son yıllarda artma eğiliminde olduğu söylenebilir. İncelenen çalışmalar neticesinde biyoloji eğitimiyle ilgili yapılan çalışmalarının diğer alanlara göre oldukça az olması dikkat çekmektedir. Çalışmalar katılımcı düzeylerine göre incelendiklerinde sadece bir araştırmada 1-5 sınıflara yer verildiği görülmektedir. Katılımcı düzeylerine göre inceleme neticesinde bir diğer önemli nokta öğretmenler ve öğretmen adaylarıyla yürütülen çalışmaların da az olması yönündedir. Öğretmen ve öğretmen adaylarının öğrencileri yetiştirecekleri düşünüldüğünde sanal laboratuvarla ilgili daha fazla katılımcı oldukları çalışmalara ihtiyaç olduğu söylenebilir. Araştırmaların yöntemsel eğilimleri incelendiğinde yaklaşık 3'te 2'sinin nicel desende ve yarı deneysel tasarımda yürütüldüğü bu kapsamda veri toplama araçları, veri analiz türleri ve güvenirlik analizlerinin de nicel paradigma etrafında şekillendiği görülmektedir. Nitel ve karma yöntemde yürütülen çalışmaların sayısı ise azdır. Bu durum fen eğitiminde sanal laboratuvar kullanımıyla ilgili derinlemesine araştırmaların yapılması ihtiyacı olduğunu göstermektedir.

Sanal laboratuvarla ilgili yapılan çalışmaların sonuçları olumlu ve olumsuz olmak üzere iki tema da toplanmaktadır. Araştırmaların genel olarak sanal laboratuvarlarla ilgili olumlu sonuçlara ulaştıkları görülmektedir. Olumsuz sonuçlar teması altında kategori ve alt kategoriler bulunmamakla birlikte olumlu sonuçlar teması altında beş kategoriye ulaşılmıştır. Bu beş kategori; sanal laboratuvarın kullanımıyla ilgili sonuçlar, laboratuvar süreçleriyle ilgili sonuçlar, duyuşsal alanla ilgili sonuçlar, bilişsel alanla ilgili sonuçlar, beceri gelişimi ile ilgili sonuçlardır. Bu sistematik derleme kapsamında sanal laboratuvarlarla ilgili ulaşılan olumlu sonuçların yanında olumsuz sonuçlar da mevcuttur. Olumsuz sonuçlara ulaşan çalışmaların sayısı az olmasına rağmen literatüre sağladıkları katkının önemli olduğu düşünülmektedir.

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Araştırmacıların Katkı Oranı Beyanı

Bu çalışmanın planlanması, yürütülmesi ve yazılı hale getirilmesinde araştırmacılar eşit oranda katkı sağlamıştır.

Destek ve Teşekkür Beyanı

Bu araştırmada herhangi bir kurum, kuruluş ya da kişiden destek alınmamıştır.

Çatışma Beyanı

Araştırmacıların, araştırma ile ilgili diğer kişi ve kurumlarla herhangi bir kişisel ve finansal çıkar çatışması yoktur.

Etik Kurul Beyanı

Bu araştırma derleme türünde olduğu için etik kurul izni gerektirmemektedir.

Appendix A: The Article That Were Examined within the Scope of the Systematic Review

The Code for the Article	Articles
A1	Ali, N., Ullah, S., & Khan, D. (2022). Minimization of students' cognitive load in a virtual chemistry laboratory via contents optimization and arrow-textual aids. Education and Information Technologies, 27, 7629-7652. https://doi.org/10.1007/s10639-022-10936-6
A2	Almazaydeh, L., Younes, I., & Elleithy, K. (2016). An Interactive and Self-instructional Virtual Chemistry Laboratory. International Journal of Emerging Technologies in Learning (iJET), 11(07), 70–73. https://doi.org/10.3991/ijet.v11i07.5853
A3	Arista, F. S., & Kuswanto, H. (2018). Virtual Physics Laboratory Application Based on The Android Smartphone to Improve Learning Independence and Conceptual Understanding. International Journal of Instruction, 11(1), 1-16. https://doi.org/10.12973/iji.2018.1111a
A4	Chiu, J. L., DeJaegher, C. J., & Chao, J. (2015). The effects of augmented virtual science laboratories on middle school students' understanding of gas properties. Computers & Education, 85, 59-73. https://doi.org/10.1016/j.compedu.2015.02.007
A5	Daineko, Y., Ipalakova, M., Tsoy, D., Bolatov, Z., Baurzhan, Z., & Yelgondy, Y. (2020). Augmented and virtual reality for physics: Experience of Kazakhstan secondary educational institutions. Computer Applications in Engineering Education, 28(5), 1220-1231. https://doi.org/10.1002/cae.22297
A6	Falode, O. C., & Gambari, A. I. (2017). Evaluation of virtual laboratory package on Nigerian secondary school physics concepts. Turkish Online Journal of Distance Education, 18(2), 168-178. https://doi.org/10.17718/tojde.306567
A7	Gunawan, G., Harjono, A., Sahidu, H., & Herayanti, L. (2017). Virtual laboratory of electricity concept to improve prospective physics teachers creativity. Jurnal Pendidikan Fisika Indonesia, 13(2), 102-111. https://doi.org/10.15294/jpfi.v13i2.9234
A8	Herga, N. R., Čagran, B., & Dinevski, D. (2016). Virtual laboratory in the role of dynamic visualisation for better understanding of chemistry in primary school. Eurasia Journal of Mathematics, Science and Technology Education, 12(3), 593-608. https://doi.org/10.12973/eurasia.2016.1224a
A9	Herga, N. R., Glažar, S. A., & Dinevski, D. (2015). Dynamic visualization in the virtual laboratory enhances the fundamental understanding of chemical concepts. Journal of Baltic Science Education, 14(3), 351-365.
A10	Hung, J. F., & Tsai, C. Y. (2020). The Effects of a virtual laboratory and metacognitive scaffolding on students' data modeling competences. Journal of Baltic Science Education, 19(6), 923-939. https://doi.org/10.33225/jbse/20.19.923
A11	Husnaini, S. J., & Chen, S. (2019). Effects of guided inquiry virtual and physical laboratories on conceptual understanding, inquiry performance, scientific inquiry self-efficacy, and enjoyment. Physical Review Physics Education Research, 15(1), 010119. https://doi.org/10.1103/PhysRevPhysEducRes.15.010119

A12	Ifthinan, D. N. M., & Atun, S. (2019). The Impact of Inquiry-Based Virtual Laboratory on Students' Inquiring Abilities. MIER Journal of Educational Studies Trends and Practices, 9(1), 50–61. https://doi.org/10.52634/mier/2019/v9/i1/1377
A13	Jagodziński, P., & Wolski, R. (2015). Assessment of application technology of natural user interfaces in the creation of a virtual chemical laboratory. Journal of Science Education and Technology, 24(1), 16-28. https://doi.org/10.1007/s10956-014-9517-5
A14	Kapici, H. O., Akcay, H., & Cakir, H. (2022). Investigating the effects of different levels of guidance in inquiry-based hands-on and virtual science laboratories. International Journal of Science Education, 44(2), 324-345. https://doi.org/10.1080/09500693.2022.2028926
A15	Kapici, H. O., Akcay, H., & Koca, E. E. (2022). Comparison of the quality of written scientific arguments in different laboratory environments. International Journal of Science and Mathematics Education, 20(1), 69-88. https://doi.org/10.1007/s10763-020-10147-w
A16	Kapici, H. O., Akcay, H., & de Jong, T. (2019). Using hands-on and virtual laboratories alone or together—which works better for acquiring knowledge and skills?. Journal of science education and technology, 28(3), 231-250. https://doi.org/10.1007/s10956-018-9762-0
A17	Kapici, H. O., Akcay, H., & de Jong, T. (2020). How do different laboratory environments influence students' attitudes toward science courses and laboratories?. Journal of Research on Technology in Education, 52(4), 534-549. https://doi.org/10.1080/15391523.2020.1750075
A18	Karlsson, G., Ivarsson, J., & Lindström, B. (2013). Agreed discoveries: students' negotiations in a virtual laboratory experiment. Instructional science, 41(3), 455-480. https://doi.org/10.1007/s11251-012-9238-1
A19	Lai, T. L., Lin, Y. S., Chou, C. Y., & Yueh, H. P. (2022). Evaluation of an inquiry-based virtual lab for junior high school science classes. Journal of Educational Computing Research, 59(8), 1579-1600. https://doi.org/10.1177/07356331211001579
A20	Penn, M., & Mavuru, L. (2020). Assessing pre-service teachers' reception and attitudes towards virtual laboratory experiments in life sciences. Journal of Baltic Science Education, 19(6A), 1092-1105. https://doi.org/10.33225/jbse/20.19.1092
A21	Puntambekar, S., Gnesdilow, D., Dornfeld Tissenbaum, C., Narayanan, N. H., & Rebello, N. S. (2021). Supporting middle school students' science talk: A comparison of physical and virtual labs. Journal of Research in Science Teaching, 58(3), 392-419. https://doi.org/10.1002/tea.21664
A22	Špernjak & Šorgo (2018) Differences in acquired knowledge and attitudes achieved with traditional, computer-supported and virtual laboratory biology laboratory exercises, Journal of Biological Education, 52(2), 206-220, https://doi.org/10.1080/00219266.2017.1298532
A23	Sullivan, S., Gnesdilow, D., Puntambekar, S., & Kim, J. S. (2017). Middle school students' learning of mechanics concepts through engagement in different sequences of physical and virtual experiments. International Journal of Science Education, 39(12), 1573-1600. https://doi.org/10.1080/09500693.2017.1341668
A24	Tatli, Z., & Ayas, A. (2013). Effect of a virtual chemistry laboratory on students' achievement. Journal of Educational Technology & Society, 16(1), 159-170. Retrieved from https://www.jstor.org/

A25	Topalsan, A. K. (2020). Development of scientific inquiry skills of science teaching through argument-focused virtual laboratory applications. Journal of Baltic Science Education, 19(4), 628-646. https://doi.org/10.33225/jbse/20.19.628
A26	Ullah, S., Ali, N., & Rahman, S. U. (2016). The effect of procedural guidance on students' skill enhancement in a virtual chemistry laboratory. Journal of Chemical Education, 93(12), 2018-2025. https://doi.org/10.1021/acs.jchemed.5b00969
A27	Wang, T. L., & Tseng, Y. K. (2018). The comparative effectiveness of physical, virtual, and virtual-physical manipulatives on third-grade students' science achievement and conceptual understanding of evaporation and condensation. International Journal of Science and Mathematics Education, 16(2), 203-219. https://doi.org/10.1007/s10763-016-9774-2
A28	Winkelmann, K., Scott, M., & Wong, D. (2014). A study of high school students' performance of a chemistry experiment within the virtual world of second life. Journal of chemical education, 91(9), 1432-1438. https://doi.org/10.1021/ed500009e
A29	Wolski, R., & Jagodziński, P. (2019). Virtual laboratory—Using a hand movement recognition system to improve the quality of chemical education. British Journal of Educational Technology, 50(1), 218-231. https://doi.org/10.1111/bjet.12563
A30	Yusuf, I., & Widyaningsih, S. W. (2020). Implementing E-Learning-Based Virtual Laboratory Media to Students' Metacognitive Skills. International Journal of Emerging Technologies in Learning, 15(5), 63-74. https://doi.org/10.3991/ijet.v15i05.12029

Appendix B: Article Review Form

Article Codes	Title	Publication Year	Subject Fields	Participant Levels	Sample Sizes	Methods	Results Concerning Virtual Laboratories	Codes After Content Analysis	Possible Categories and Subcategories