Yıldız Journal of Educational Research
Web page info: https://yjer.yildiz.edu.tr
DOI: 10.14744/yjer.2025.010

Systematic Review / Sistematik Derleme

Virtual Laboratory Applications in Science Education: A Systematic Synthesis of National Postgraduate Theses

Fen Eğitiminde Sanal Laboratuvar Uygulamaları: Ulusal Lisansüstü Tezlere Dayalı Sistematik Bir Sentez

Kevser ARSLAN, Vildan BOZ KÖMÜ, Aslı GÖRGÜLÜ

Yıldız Technical University, İstanbul, Türkiye

Yıldız Teknik Üniversitesi, İstanbul, Türkiye

ARTICLE INFO

Article history
Received: 22 August 2025
Revised: 14 November 2025
Accepted: 17 December 2025

Key words:
Technology, Science Education, Virtual Laboratory Applications, Synthesis Study.

ABSTRACT

In this study, it is aimed to examine the postgraduate thesis studies related to virtual laboratory applications in science education. Based on the purpose of the study, 54 national postgraduate thesis studies within the scope of virtual laboratory applications in science education between 2010-2024 were analyzed based on the determined criteria. The study was carried out as a systematic synthesis study, and the thesis studies evaluated within the framework of the study were examined objectively. As a result of the study, it was revealed that the theses examined aimed to investigate the effects of virtual laboratories on academic achievement, scientific process skills, 21st-century skills, behaviour, and attitude. It has been determined that the studies are generally based on quantitative design, the study group is aimed at secondary school students, data analyses are carried out with statistical analyses, and achievement tests and scales are used as data collection tools. In addition, it was mentioned that the studies mostly focused on electricity and force-motion units and the positive effect of virtual laboratory applications on many variables. In the context of the results of the study, considering the positive impact of virtual laboratory applications in science education on student achievement, concept learning, and attitudes, the use of virtual laboratories in science education is recommended.

MAKALE BİLGİSİ

Makale Hakkında
Geliş tarihi: 22 Ağustos 2025
Revizyon tarihi: 14 Kasım 2025
Kabul tarihi: 17 Aralık 2025

Anahtar kelimeler:
Teknoloji, Fen Eğitimi, Sanal Laboratuvar Uygulamaları, Sentez Çalışması.

ÖZ

Bu çalışmada, fen eğitiminde sanal laboratuvar uygulamaları ile ilgili yüksek lisans tez çalışmalarını incelemek amaçlanmıştır. Çalışmanın amacına uygun olarak, 2010-2024 yılları arasında fen eğitiminde sanal laboratuvar uygulamaları kapsamında yapılan 54 ulusal yüksek lisans tez çalışması belirlenen kriterlere göre analiz edilmiştir. Çalışma sistematik bir sentez çalışması olarak gerçekleştirilmiş ve çalışma kapsamında değerlendirilen tez çalışmaları objektif bir şekilde incelenmiştir. Çalışma sonucunda, incelenen tezlerin sanal laboratuvarların akademik başarı, bilimsel süreç becerileri, 21. yüzyıl becerileri, davranış ve tutum üzerindeki etkilerini araştırmayı amaçladığı ortaya çıkmıştır. Çalışmaların genel olarak nicel tasarıma

*Corresponding author / Sorumlu yazar
*E-mail address: arslankevser96@gmail.com

dayandığı, çalışma grubunun ortaokul öğrencilerini hedeflediği, veri analizlerinin istatistiksel analizlerle yapıldığı ve veri toplama aracı olarak başarı testleri ve ölçeklerin kullanıldığı belirlenmiştir. Ayrıca, çalışmaların çoğunlukla elektrik ve kuvvet-hareket üniteleri ile sanal laboratuvar uygulamalarının birçok değişken üzerinde olumlu etkisine odaklandığı belirtilmiştir. Çalışmanın sonuçları bağlamında, fen eğitiminde sanal laboratuvar uygulamalarının öğrenci başarısı, kavram öğrenimi ve tutumlar üzerindeki olumlu etkisi göz önüne alındığında, fen eğitiminde sanal laboratuvarların kullanılması önerilmektedir.

Cite this article as: Arslan, K., Boz Kömü, V., & Görgülü, A. (2023). Virtual Laboratory Applications in Science Education: A Synthesis Study. *Yıldız Journal of Educational Research, 10*(2), 118–134.

INTRODUCTION

Technology, which gains value in education and training environments with each passing day, also shows its reflections in the field of science education. Technology comes to the fore in the effort to make science education more effective, to make learning meaningful, and to make science education active for both the teacher and the learner. Akgül et al. (2018) stated that the increase in digitalization in education, which stands out with the progress of science and technology, reveals the orientation and desires of young people in this field. With this situation, he also emphasized that distance education systems, smart board applications and virtual laboratories, especially science teaching, will be important elements within the framework of their reflections on educational environments. By making use of different technologies in science education environments, it should be focused on integrating and enriching technology in the field of science. Especially in laboratory environments, which are extremely important in science education, the tendency to digitalization will make science education more qualified. Laboratories are expressed as one of the most effective applications used in science teaching (Koç Ünal & Şeker, 2020).

Laboratory applications are applications that add a new dimension to the lessons as well as drawing a different perspective. Although its emergence was to prove knowledge, it has become environments where knowledge is discovered independently, whether individually or in group accompaniment (Tatlı & Ayas, 2010). It is important to use laboratories in school environments, which can positively affect learning by creating a basis for individuals to learn by doing. However, unsuitable conditions encountered in schools can minimize the effective use of laboratories. The high number of students, inadequacy of classrooms and lack of equipment can be listed as some obstacles in the use of laboratory environments. The high cost of laboratories or the limited areas of budget and technical expertise create problems in their use in schools (Ahuja et al., 2015; Nivalainen et al., 2010). In addition, if the necessary security measures are not taken in schools, health problems may arise for students. The existence of these obstacles has caused virtual laboratories to gain importance (Deepika et al., 2021; Karagöz Mırçık & Saka, 2016; Pınar & Dönel Akgül, 2021). With the emergence of virtual laboratories as alternatives that create a safe and low-cost solution (Hsu & Thomas, 2002), the use of laboratories in schools will be possible. Therefore, it can be stated that virtual laboratories are applications that can be used as a complement to traditional laboratory environments or instead of traditional laboratories. The existence of virtual laboratories, which emerged as a result of technological developments and can be used alongside applied laboratories, is emphasized (De Jon et al., 2013).

The application areas of virtual laboratory environments, one of the latest trends in science education, in science teaching are increasing day by day. Virtual laboratories, which gain value by aiming to meet many learning needs in the field of science teaching, are becoming popular applications. Virtual laboratories by İnce et al. (2014); It is explained in the form of programs that combine model, simulation and information technology to create a highly interactive environment adapted to the needs of students and teachers. El Kharki et al. (2021) define it as an excellent approach that enables students to make sense of science by showing scientific phenomena through automatic or virtual practical activities based on computer simulations. On the other hand, it can also be expressed as environments where experiments can be controlled partially or completely by conducting simulations or animations in an online environment. In addition, it is pointed out that although the virtual laboratory does not contain physical equipment, it provides the opportunity to observe the usage processes and the final product (Chan & Fok, 2009). De Jong et al. (2013) explained that students can investigate scientific phenomena by using virtual labs tools, data collection techniques, models and science theories. Virtual laboratories offer appropriate activities that motivate students with simulations that are meaningful and can serve main purposes compared to the traditional method. In this direction, students transform their theoretical knowledge into practice and create a feeling of real laboratory environment (Tatlı & Ayas, 2011). It can also be explained as active interactive learning environments that allow individuals to experiment independently of the place by making use of technological opportunities (Kaba, 2012).

The advantages of virtual laboratories such as eliminating inadequate laboratory conditions (Duman & Avcı, 2016) and minimizing the loss of time during the execution of experiments (Tatlı & Ayas, 2010), reaching the experiments at the desired time and carrying out or renewing the experiments without worrying about materials are mentioned. (Tatlı & Ayas, 2011; Wolf, 2009). It can also encourage students to work towards finding solutions to the problems they face (Günlü, 2020). In the science education environment, it can provide individuals with the opportunity to work in cooperation and in groups. However, it can be effective in students' enjoyment and motivation in the learning environment (Jensen et al., 2004). It is also important for students to increase their knowledge of the field, develop their inquiring skills and gain scientific process skills (Gunawan et al., 2019; Kapıcı et al., 2022; Kapıcı et al., 2019). On the other hand, it can act as a tool for users to acquire problem solving, planning and creative thinking activities (Gunawan et al., 2017; Sapriadil et al., 2019). Bozkurt & Sarıkoç (2008), on the other hand, state that a more effective teaching in a shorter time with cheaper cost for students can be realized through virtual laboratory. Karagöz Mırçık & Saka (2016) revealed that virtual laboratories increase student creativity in science teaching, make the lesson fun, provide visualization, associate it with daily life and increase student motivation for the lesson. Duman & Avcı (2016), on the other hand, mention that one of the important features of virtual laboratories is that they allow the design of experiments suitable for many achievements in the field of science.

In the literature, there are many studies indicating that virtual laboratory applications are effective on student success in science teaching. (Akkağıt & Tekin, 2012; Bozkurt, 2008; Büyükkara, 2011; Çinici et al., 2013; Hawkins & Phelps, 2013; Herga et al., 2016; Kapıcı et al., 2018; Koç Ünal & Şeker, 2020; Mutlu, 2015; Tekbıyık & Ercan, 2015; Tüysüz, 2010). On the other hand, studies indicating that students gain conceptual understanding (Kollöffel, De Jong, 2013; Moshell & Hughes, 2002), studies that show that students can positively affect their attitudes (Açıksoy & İşlek, 2017; El Kharki et al. 2021; Faour & Ayoubi, 2018; Hawkins & Phelps, 2013; Sarı Ay & Yılmaz, 2015) and studies emphasizing that it may affect communication skills (Sapriadil et al., 2019) were also reached. In addition, the existence of studies in which positive opinions about virtual laboratory applications are presented is striking (Açıksoy & İşlek, 2017; Ekici, 2015; Erdan, 2014; Pınar & Dönel Akgül, 2021).

In the literature, it is pointed out that besides the many advantages that virtual laboratory applications offer to science teaching, there are also disadvantages. It is stated that in the virtual environment, unlike physical laboratory environments, direct experiments cannot be done by hand, thus reducing the ability of students to recognize hand skills and tools. Therefore, it was emphasized that virtual laboratories contradict the principle of students' learning by doing (Akgül et al., 2018; Çinici et al., 2013). Similarly, Hawkins & Phelps (2013) explain that one of the main concerns about virtual lab applications is the inability to learn laboratory techniques by students. In addition, virtual laboratories may bring some limitations in terms of implementation. The need for some programs used in the virtual environment to require knowledge of use and powerful hardware, the additional cost of the programs, and the time consuming to learn are considered to be the disadvantages of virtual laboratory applications (Deepika et al., 2021).

The synthesis studies process provides the opportunity to reveal important meanings about the subject that is aimed to be studied (Brown, 2017; Earley, 2014; Erwin, Brotherson & Summers, 2011; Hannes & Macaitis, 2012; Liao & Hitchcock, 2018; Mesutoğlu & Baran, 2021). It can be explained as the process of revealing different and similar qualities based on the objective analysis and interpretation of the studies on a determined subject (Au, 2007; Çalık & Sözbilir, 2014; Dinçer, 2018; Polat & Ay, 2016). Creating a rich resource by providing access to all studies on the field (Bağ & Çalık, 2017; Ültay & Çalık, 2012), revealing the common tendencies of the studies (Bağ & Çalık, 2017; Çalık et al., 2005) and providing a critical perspective (Liao & Hitchcock, 2018) highlight the synthesis method.

It is obvious that virtual laboratories in science teaching have an important position in terms of both the teacher and the learner. Considering its importance in science, the examination of virtual laboratory studies in the literature has come to the fore. The increase in the number of virtual laboratory studies carried out in our country and the trend in this field reveal the need for synthesis studies to be conducted in this field. A synthesis study can be valuable in terms of drawing a framework for the virtual laboratory, developing an in-depth understanding and creating a new perspective on the laboratory applied in the virtual environment. On the other hand, it will be possible to see the advantages and disadvantages of virtual laboratories in science teaching closely. However, by examining the existing studies, it is foreseen that their future use can be shaped by determining how virtual laboratories are applied in science teaching. In addition, detecting the deficiencies that may be encountered in virtual laboratory applications and making improvement studies in this direction can be counted among its other outputs. On the one hand, it is expected to be a source of ideas for researchers who will work on this subject, and on the other hand, it is expected to guide educators who aim to implement virtual laboratories in classroom environments. Based on these reasons, in this study, it is aimed to synthesize national postgraduate thesis studies on virtual laboratory applications in science education between 2010-2024.

Answers are sought to the research questions created based on the determined study purpose.

1. For what purpose and purposes were postgraduate thesis studies carried out?
2. Which research patterns were used in postgraduate thesis studies?
3. Which study group or sample group was preferred in graduate thesis studies?
4. Which data collection tools were used in postgraduate thesis studies?
5. Which data analysis methods were used in postgraduate thesis studies?
6. What are the science subject areas in which virtual laboratory applications are carried out in graduate thesis studies?
7. What are the application periods in which virtual laboratory applications are carried out in postgraduate thesis studies?
8. What types of virtual laboratory applications are preferred in postgraduate thesis studies?
9. What are the general results obtained for virtual laboratory applications in postgraduate thesis studies?
10. What are the most important suggestions for virtual laboratory applications in graduate thesis studies?

METHOD

Study Pattern

This research is a systematic synthesis study based on a qualitative research approach, aiming to synthesize the theses written for virtual laboratory applications used in science education. Search can also be specified as a synthesis protocol that includes reviewing, decision-making and analysis methods in line with the determined selection criteria and that aims to clearly explain the findings. In this context, since the current study aims to draw a general picture of the quantitative and qualitative studies of virtual laboratory applications used in science education and to create a framework for the individuals concerned in the field of education, it was decided to conduct a synthesis study. In order to ensure the clarity of the synthesis work carried out, the research steps (Çalık &Wiyarsi, 2021; Suri & Clarke, 2009) are given in Figure 1 in general.

The current research process steps are shown in Figure 1. The focus of the study set forth in the research has been systematically advanced. In accordance with the findings

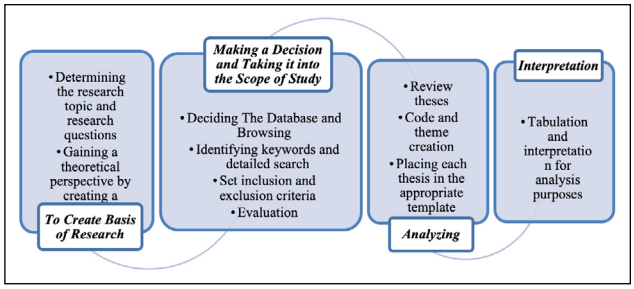

Figure 1. Research steps followed in the study.

obtained, the data were interpreted, and the synthesis process was terminated.

Research Sample and Data Collection

In accordance with the purpose of the research, the studies determined in the literature were determined as samples. In the first stage, studies on virtual laboratory applications in science education were determined. In the study, Google Scholar, YÖK National Thesis Center, Proquest databases were browsed. Browsing started in October 2021 and were completed in December 2024. After the general browsing, it was determined that there was adequate research for the synthesis study, and it was decided to study on the basis of the determined subject. After the examinations, it was seen that the concept of virtual laboratory was used directly in some thesis studies, and animations and simulations in which the concept of virtual laboratory came to the forefront in some studies. In the literature, it has been clearly understood that virtual laboratory applications used in science education include virtual laboratory, simulation, and animation applications. In this direction, the keywords to be searched were decided. In order to access the thesis studies on virtual laboratory applications used in science education in detail, a detailed search was started, and keywords were determined for this stage. The words "Virtual Laboratory", "Animation" and "Simulation" were searched in Turkish and English languages. The fact that most of the articles published after the browsing were produced from theses revealed the reason for the analysis of theses. Therefore, it was deemed appropriate to determine the scope of the theses written in the national field within the framework of the study. In the next stage, inclusion and exclusion criteria were established based on the study purpose, after a clearer screening. The results were narrowed down by selecting the subject area of "Education and Training" in the YÖK National Thesis Center with the searches made with the determined keywords. The YÖK database was chosen because the database to be researched should be uploaded to the YÖK National Thesis Center for all the theses written in the national field. However, in order to ensure that national theses that may be overlooked, Google academic and ProQuest databases were also checked and confirmed. The screening steps followed in the study are given in Figure 2 in detail.

When Figure 2 is examined, the detailed stages of the screening steps followed in the synthesis study carried out in the present study are seen. The number of thesis studies reached at each step is expressed in the figure. After the scans with the specified keywords, the evaluation process was started in line with the determined parameters and the studies included in the research were evaluated by filtering them in order according to four basic criteria. First of all, it was taken into account that the studies were national thesis studies conducted between 2010-2024 in the second step, it was checked whether the studies within the determined

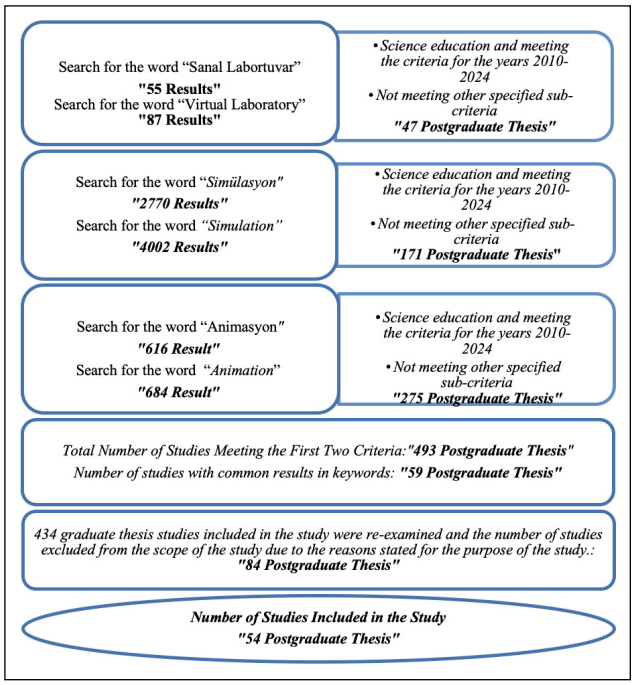

Figure 2. Browsing steps followed in the study.

years were national theses. Considering the criterion that the studies covering the range of years should be made for science education, studies conducted in different branches and oriented to measurement and evaluation were excluded. In addition, although it seems to be related to the field of science, studies that do not overlap with science have been tried to be kept apart. (For example, a study conducted for natural disasters but not directly related to science or a health study focused on anatomy). Mixed computer aided teaching studies without central animation and simulation is excluded from the scope (For example, a study in which all methods such as video, slide, animation, etc. are combined). Similarly, studies in which animation is an auxiliary tool are not included (For example, animations, movies, and concept cartoons). Finally, some studies that moved away from the virtual laboratory focus, such as smart boards and mobile applications, were also screened. After the elimination process, which was basically carried out in four stages, and after the common results in the keywords were checked, 84 graduate theses passed the screening process. At the last stage, the contents of 84 theses were examined one by one and subjected to the second elimination process. In the elimination process in the second round, thesis contents and application processes were examined. Theses based on animations and simulations, theses in which students do not make trial and error on the program (for example, studies in which animations are watched by students in classes), animation-based theses with slow transition (animation progressing at slow speed to students), web 2.0 applications and augmented reality applications. These are excluded from the scope of the study. After the elimination processes, 30 theses out of 84 theses were excluded from the evaluation. The data set to be analyzed with 54 national postgraduate thesis studies in accordance with the criteria determined in the context of the study has taken its final form.

54 national thesis studies included in the study were coded as T1, T2, T3… T54. "T1" refers to the coded national thesis number 1. The thesis studies in the national field analyzed within the scope of the research are given in Appendix 1. The distribution of the postgraduate theses examined within the scope of the study by types and years is given in Table 1.

The distribution of national theses related to virtual laboratory applications in science education in the last twelve years is shown Table 1. In the last fifteen, 54 theses have been reached in the national fields that meet the analysis criteria. It obvious that 45 of the postgraduate theses accessed are post graduate theses and 9 are doctoral theses. It is understood that the most thesis related to virtual laboratory applications was written in 2024 and the least thesis was written in 2010. In 2016, there is no postgraduate thesis related to the current subject area was found.

Coding and Analysis of Data

Efforts were made to analyze and transfer the thesis studies, which were evaluated in the research objectively. While analyzing the thesis studies, content analysis was used by evaluating them based on theme and code operations. The studies were examined in two stages. In the first

Table 1. Thesis Studies on Virtual Laboratory Applications in Science Education and Their Distribution by Years

Studying Years	National Graduate Theses		Total
	Postgraduate	Doctorate	
2010	1	-	1
2011	2	1	3
2012	2	-	2
2013	1	-	1
2014	3	-	3
2015	4	3	7
2016	-	-	-
2017	1	1	2
2018	4	1	5
2019	5	-	5
2020	1	1	2
2021	4	1	5
2022	5	-	5
2023	5	1	6
2024	7	-	8
Total	45	9	54

stage, all the studies that were evaluated were examined one by one. General codes and themes were created to include each study examined. Based on the studies, general coding that would be suitable for the theses was decided and code templates were determined. In the second stage, the studies were placed under the appropriate code title by examining each study based on the determined codes. If it is suitable for more than one code, it is included under the code that may be highly likely to be included. During the analysis process, the coding that was deemed necessary to make significant changes were rearranged. At the last stage, the analyzes were reviewed and last controls were made. Analysis data are conveniently presented in tables (Au, 2007; Brown, 2017; Calık & Sozbilir, 2014; Calık & Wiyarsi, 2021).

The stages of analysis and coding process of thesis studies are given below, respectively. In the first stage, each study was tabulated by determining the thesis names, thesis year, thesis type and authors. By examining the aims of the thesis studies, those showing similarities and differences in line with the thesis objectives were came together and placed in the appropriate code. The research patterns of the thesis studies were examined under the themes of qualitative, quantitative, and mixed patterns. Studies such as experimental studies and survey studies were collected quantitatively, studies such as case, phenomenon and science were collected qualitatively, and studies in which both quantitative and qualitative research methods were used together were gathered under mixed themes. The sample and study groups of the thesis studies were analyzed by considering their education and training levels. Studies for students were placed under the themes of primary, secondary, high school and undergraduate level, and groups of teachers were placed under the theme of teachers. The study groups that did not match the determined codes were gathered under the other code. If different sample levels were used in some studies, it was necessary to place them in two different codes. For example, in a study, it was deemed appropriate to include both teachers and students, and to place study groups under two different themes. Samples such as lecturers and documents, which can be expressed from studies using different samples from the general, were included in the other category. The data collection tools of the thesis studies were basically examined. Academic achievement tests and scales (attitude, motivation, etc.), all interviews (structured, semi-structured, focus group, etc.), open-ended questions were placed under the heading of data collection tools and a graph was created. The data analysis methods of the thesis studies were analyzed similarly. Dependent and independent t-test analyses, ANOVA test, covariance test etc. analyzes were included under the statistical analyzes category, and content and descriptive analyzes were included under the qualitative analyzes theme. Demographic analyses, frequency analyses, standard deviation and mean data analyzes were collected in descriptive analyses. The programs used for virtual laboratory purposes in the thesis studies, the units and subject areas in which the programs are used, and the experimental processes in applying the program are also analyzed and presented in graphics. When the results obtained in the thesis studies were examined, it was seen that more than one conclusion was reached. While analyzing the results obtained in the thesis studies, the main result, which is the basis of the study, was taken as a basis. Finally, in the thesis studies, the analysis of the prominent suggestions of the virtual laboratory and its applications was also carried out and given in tables. The analysis process of the thesis studies was completed in line with the steps followed.

Research validity and reliability

In order to ensure the validity and reliability of the research, due care was taken in the processes of reaching the studies, deciding on the inclusion process and analyzing them. In the process of inclusion of theses in the study, the opinions of experts in the field of science were consulted regarding the decision-making criteria. In addition, the reduction of 84 thesis studies to 54 studies was carried out by two researchers with postgraduate education degrees. In the theses where there was a difference of opinion, the opinions of the expert faculty members were taken. In particular, during the analysis process, code and theme checks were carried out repetitively to ensure consistency. In addition, the analysis process was confirmed and progressed through interviews held with field experts at specified time intervals. The reliability calculation for the study was performed using the reliability formula by Miles & Huberman (2016). The numbers of 'agreement' and 'disagreement' were determined from the ratings of the researchers and experts. The reliability coefficient was calculated by dividing the sum of the agreement and disagreement counts by the total and multiplying by 100. The calculated value should be at least 80 (Miles & Huberman, 2016). It was determined that there was a high agreement of 95% among the researchers. Therefore, it has been concluded that reliability has been established among the evaluators. At each stage of the synthesis study, it was carefully completed under the control of the researcher.

RESULTS

In this part of the research, graphics and tables of the findings obtained from the studies examined are included. In Table 2, the findings related to the aims of the thesis studies about the virtual laboratory are given.

As can be seen in Table 2, the studies related to the virtual laboratory were carried out in order to examine the effects of the training given at a high rate on the academic achievement, scientific process skills, 21st century skills, behaviours and attitudes of the participants. In addition, 13

Table 2. Findings Regarding The Aims of Virtual Laboratory Studies

Aims	Thesis Studies	Frequency
The effect of training given with virtual laboratory on academic achievement, scientific process skills (SPS), 21st century skills, behaviour, and attitude	T1, T2, T3, T4, T5, T6, T7, T8, T10, T11, T13, T14, T15, T16, T17, T19, T20, T21, T22, T23, T24, T26, T27, T28, T31, T33, T34, T35, T36, T37, T38, T39, T41, T42, T45, T46, T47, T48, T50, T51, T52, T54	42
The effect of training given with virtual laboratory on conceptual permanence, cognitive structure, and learning	T1, T5, T8, T12, T22, T30, T31, T38, T39, T42, T44, T47, T54	13
Opinions on virtual laboratory applications	T9, T11, T35, T39, T40, T43, T49	7
The use of the virtual laboratory in determining students' conceptual knowledge and structures, identifying, and eliminating is conceptions	T18, T19, T21, T22, T25, T38, T40	7
Comparison of different laboratory environments (virtual, physical, a combination of two, etc.)	T3, T6, T12,T21, T26, T32, T51	7
Developing and evaluating a virtual laboratory	T31, T32, T42, T43, T48, T53	6
The effect of the virtual laboratory on students' awareness, interest, and motivation towards the lesson.	T7, T20, T30, T34, T35, T37	6
The effect of the virtual laboratory on the skills of argumentation, questioning and hypothesis making	T4, T9, T19	3
The effect of the gender factor in the teaching of the subjects	T32	1
The effect of virtual laboratory applications on entrepreneur ship skills	T24	1

studies aimed to investigate the effects of virtual laboratory training on conceptual permanence, cognitive structure and learning, while 6 studies aimed to develop and evaluate virtual laboratories. In 7 studies, it was determined that the views on virtual laboratory applications were determined and in 7 studies, it was determined that students' conceptual knowledge and structures were determined, and misconceptions were determined and eliminated. In addition, it was seen that 7 studies aimed to compare different laboratory environments and to investigate the effect of the study on the awareness and motivation of virtual laboratory students for the lesson. It is seen that 3 studies aimed to investigate the effect of argumentation, questioning and hypothesis-building skills, and 1 study aimed to investigate the effect of gender factor and the effect of virtual laboratory applications on entrepreneurship skills.

In Figure 3, the distribution of the thesis studies examined according to the research method is given.

When Figure 3 is examined İt is seen that 39 of the studies conducted are quantitative research methods. It is understood that 10 of the thesis studies were conducted in mixed design and 5 of them were conducted in qualitative research method. The research designs of the analyzed studies are given in Figure 4.

When Figure 4 is examined, it is seen that 29 of the studies conducted were in a quasi-experimental design. It is seen that five of the thesis studies are specified as experimental design, while the research design of twelve of them is not specified. It is seen that 3 of the studies was conducted in a case study. Also 2 of the studies was conducted quantitative descriptive and 3 studies was weak experimental design.

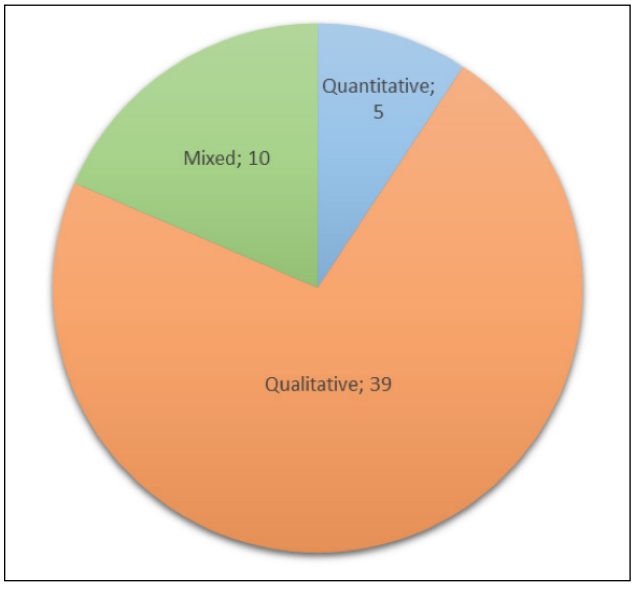

Figure 3. Distribution of virtual laboratory studies by research methods.

In Figure 5 the distribution of the thesis studies examined according to the research groups is given.

When Figure 5 is examined, it can be seen that secondary and high school students were chosen as the research group in the researches about virtual laboratory in general. It is understood that the studies are carried out on the basis

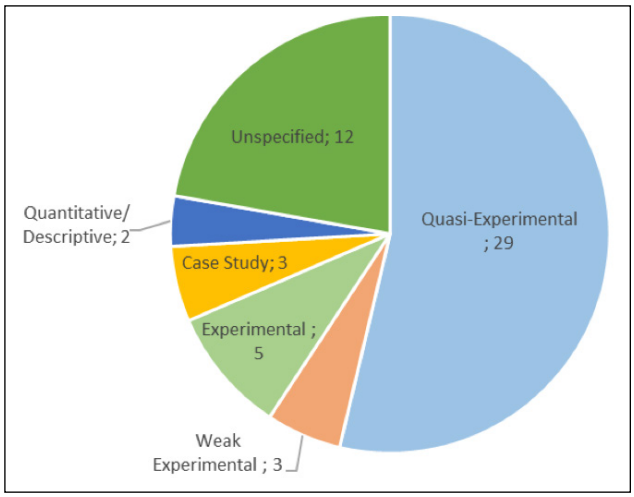

Figure 4. Distribution of examined studies by research designs.

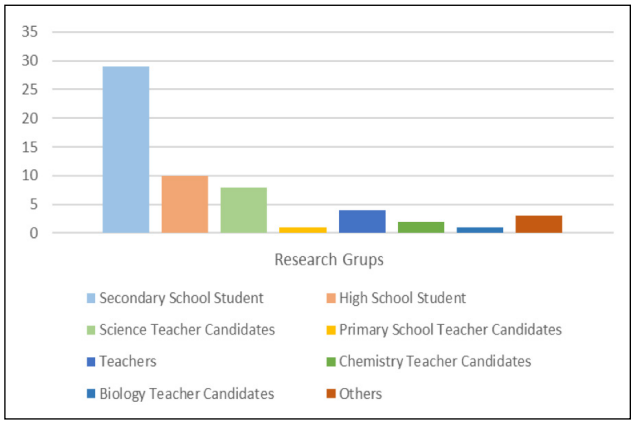

Figure 5. Distribution of virtual laboratory studies by research groups.

of students. In addition, it has been determined that in the studies conducted, it was also studied with science, chemistry, biology and classroom teacher candidates. Following this, the research groups and their thesis codes are given in Table 3 in detail.

When Table 3 is examined, it is understood that 29 of the thesis studies were carried out for secondary school students and 10 of them were for high school (secondary education) students. It is seen that it has been studied with individuals studying in the fields of science, chemistry, classroom and biology. In addition, 4 thesis studies were determined as the working group of the teachers.

In Figure 6, the distribution of the studies examined within the scope of the research according to the subjects is given.

When the results in Figure 6 are examined, it is seen that the Electricity Unit (5 studies) and the Force and Motion Unit (8 studies) were mostly preferred as the subjects in the theses examined within the scope of the research. It has been determined that studies have been carried out on subjects such as Sound and Its Properties, Matter and Its Properties, States of Matter and Heat, Optics, and Chemical Reactions. In addition, Figure 6 shows that the studies on the virtual laboratory focus on physics.

In Figure 7, the data collection tools used in the studies examined within the scope of the research are given.

When the results of the data collection tools in Figure 7 are examined achievement tests were used in 48 studies. Survey/scale in 27 studies, interview method in 19 studies, observation in 2 studies and prepared forms in 3 studies were used as data collection tools.

In Table 4, the results of the data analysis methods used in the theses examined within the scope of the research are given.

When Table 4 is examined, it is seen that statistical analyzes are mostly used with 49 studies in data analysis. In addition to this, it is understood that 13 studies were analyzed using qualitative data analysis methods and 5 studies were analyzed using descriptive analysis methods.

In Figure 8, the distribution of virtual laboratory studies according to the implementation period is given.

Table 3. Distribution of Virtual Laboratory Studies by Research Group

Research Groups	Secondary School Students	High School Student	Teacher Candidates				Teacher	*Others
			Science	Primary School	Chemistry	Biology		
Thesis Code	T1, T3, T4, T6 T7, T8, T10, T14, T15, T16, T17, T19, T20, T21, T23, T24, T25, T26, T27, T28, T29, T30, T32, T33, T34, T38, T46, T51, T52	T2, T11, T18, T31, T36, T43, T45, T48, T53, T54	T12, T13, T22, T35, T39, T41, T42, T47	T37	T48, T50	T50	T9, T31, T40, T43	T5, T44, T49
Total	29	10	8	1	2	1	4	3

* Other: Studies that do not use samples or that use different samples from the general (For example, instructors, documents, etc.)

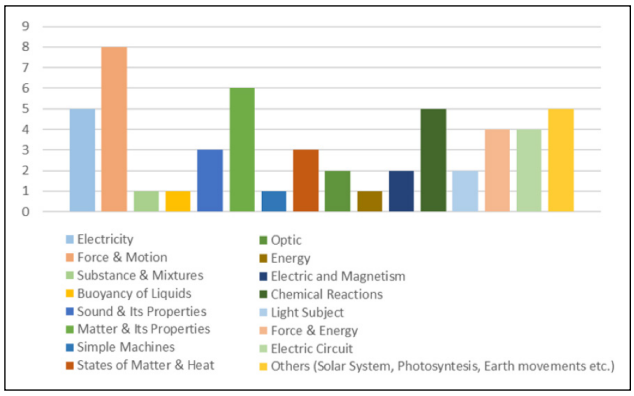

Figure 6. Distribution of virtual laboratory studies by subject.

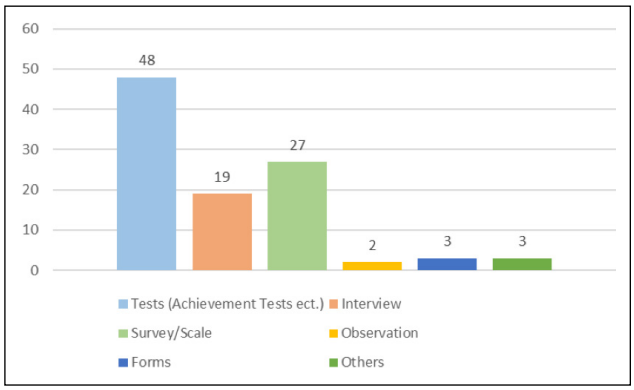

Figure 7. Distribution by data collection tools used in virtual laboratory studies.

When Figure 8 is examined, when the graph of the application times is examined, it is seen that the application period of 31 theses is between 2-6 weeks, and the application period of 9 studies is between 7-12 weeks. In 4 studies, it was determined that the application period was between 6-12 hours, 3 studies did not apply, and in 6 studies, the situation related to the application was not specified.

Table 5 presents the findings related to the results of the researches about the virtual laboratory.

When Table 5 is examined, it is stated that virtual

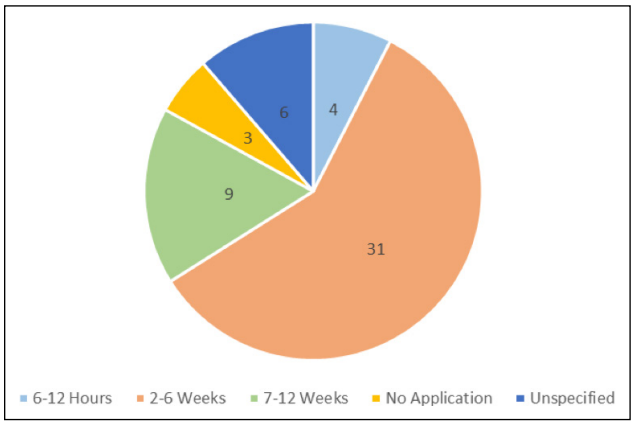

Figure 8. Distribution of virtual laboratory studies by implementation periods.

laboratory applications have positive effects on participants' academic achievement, scientific process skills, attitude towards the course, and have positive effects on conceptual changes, eliminating misconceptions and concept retention. In addition, it was seen that the virtual laboratory increased the interest and motivation of the participants and had a positive effect on entrepreneurship, 21st century skills, argumentation and hypothesis-building skills. It has been revealed that the practices of virtual laboratory studies have a positive effect on the learning of the participants, and virtual laboratories allow the same experiments to be repeated over and over without equipment limitations. In addition to these, in some studies, it was concluded that there was no statistically significant difference between the use of traditional and virtual laboratories in terms of participants' understanding of the subject, attitudes, and academic achievements, and that some of the participant teachers never used virtual laboratory activities in their classes.

In Figure 9, their distribution according to the programs preferred in virtual laboratory studies is given.

When the findings in Figure 9 are examined, it is seen that the virtual laboratory/animation/simulation applica-

Table 4. Data Analysis Methods Used in Virtual Laboratory Studies

Data Analysis	Statistical Analysis	Descriptive Analysis	Qualitative Data Analysis
Thesis Code	T1, T2, T3, T4, T5, T6, T7, T8, T10, T11, T12, T14, T15, T16, T17, T19, T20,T21, T22, T23, T24, T25, T26, T27, T28, T29, T30, T31, T32, T33, T34, T35, T36, T37, T38, T39, T40, T41, T42, T44, T45, T46, T47, T48, T50, T51, T52, T53, T54	T2, T7, T32, T43, T44	T8, T9, T13, T16, T17, T18, T20, T25, T35, T38, T39, T47, T49
Total	49	5	13

* Statistical Analysis: such as t-test, ANOVA, covariance analysis.

Table 5. Findings Related to the Results of Virtual Laboratory Studies

Results	Thesis Studies	Frequency
It has been observed that the trainings given with the virtual laboratory increase/ develop their academic achievement and scientific process skills (SPS) and positively affect the students' attitudes towards the course.	T1, T2, T3, T4, T7, T10, T11, T12, T13, T14, T15, T16, T17, T19, T20, T22, T24, T26, T27, T28, T32, T33, T34, T35, T36, T37, T38, T39, T41, T44, T45, T48, T50, T51, T52, T53, T54	37
It has been determined that the conceptual changes of the participants have positive effects on the elimination of misconceptions and the permanence of the concept.	T5, T19, T21, T22, T25, T26, T31, T38, T39, T42, T44	11
It was concluded that the participants had a positive effect on their learning.	T6, T8, T16, T18, T23, T47	6
It was observed that the virtual laboratory increased the interest and motivation of the participants.	T20, T31, T34, T37, T43	5
It was observed that the participants had a positive effect on entrepreneurship, 21st century skills, argumentation, and hypothesis-building skills.	T23, T24, T29	3
There was no statistically significant difference between traditional and virtual laboratory use in terms of participants' understanding of the subject, attitudes, and academic achievements.	T30, T46	2
It was determined that some of the participating teachers never used virtual laboratory activities in their classes.	T9, T50	2
It has been determined that virtual laboratories allow the same experiments to be repeated many times without equipment limitations.	T49	1
Total		67

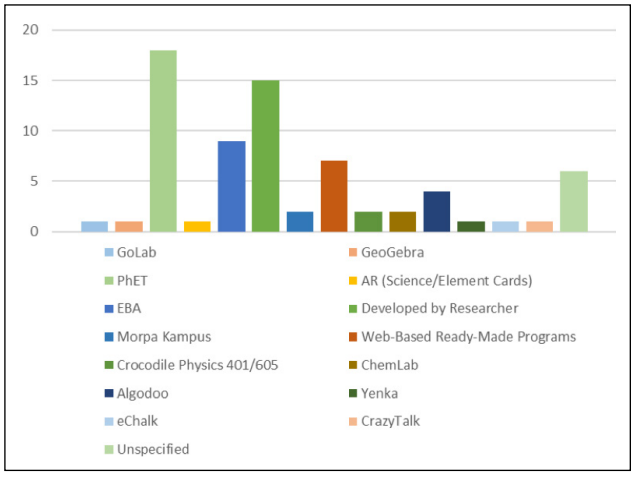

Figure 9. Distribution of virtual laboratory studies by preferred programs.

tions used in 15 studies were developed by the researcher, and PhET application was used in 19 studies. Then, web-based ready-made simulations (7 studies), EBA (9 studies), Crocodile Physics (2 studies), ChemLab (2 studies) follow. In addition, GoLab, GeoGebra, AR science cards, Yenka, eChalk and CrazyTalk applications were used in one study. In 6 studies, it is seen that the applications or programs used are not specified.

Table 6 includes the findings regarding the recommendations made in the studies examined.

When Table 6 is examined, it is seen that the suggestions given as a result of the studies related to the virtual laboratory are the suggestions given for reasons such as allowing dangerous and difficult experiments to be carried out in places where laboratories are insufficient or not available. In addition, it is seen that there are suggestions for the use of abstract subjects that are difficult in learning and for planning their teaching, developing activities and curricular arrangements. In addition, it is seen that there are suggestions for its use for support purposes such as activity, problem solving or course repetition, planning the virtual laboratory application process and conducting studies at different teaching levels. In addition, it has been determined that suggestions are made for teacher training programs and curricula, for realizing student-centered, active teaching, and for investigating the effects of learners' predisposition towards technology on virtual laboratory.

Table 6. Findings Regarding the Suggestions Included in Virtual Laboratory Studies

Suggestions	Thesis Studies	Frequency
In places where laboratories are inadequate or lacking, it allows dangerous and difficult experiments to be carried out, traditional laboratory costs, ease of use, etc. Suggestions for choosing an alternative for reasons	T5, T10, T21, T26, T28, T30, T32, T34, T37, T38, T39, T42, T51, T53	14
Suggestions forth euse of virtual laboratories in learning difficult and abstract subjects	T1, T4, T15, T18, T23, T44, T45, T48, T50	9
Suggestions for planning virtual laboratory teaching, developing activities and curricular arrangements	T3, T11, T12, T14, T24, T25, T31, T40	8
Recommendations for teacher training programs and curricula	T7, T8, T9, T16, T35, T46	6
Recommendations for planning the virtual laboratory implementation process	T2, T13, T20, T23, T27, T41	6
Virtual labs can be used for activities, question solving or course repetition, etc. Suggestions for support use	T6, T29, T43, T49, T52	5
Suggestions for studies at different teaching levels	T17, T22, T35, T54	4
Recommendations forth euse of virtual laboratories for student-centered, active teaching	T30, T36	2
Suggestions for investigating the effect of learners' predisposition towards technology on virtual laboratory	T19, T47	1
Total		55

DISCUSSION

In the study, postgraduate theses on virtual laboratory in science education in our country were examined and their results were discussed. The effects of virtual laboratory use on variables such as academic achievement, scientific process skills, and attitude were examined in general terms in the studies prepared on virtual laboratory. In addition, it is expected that the basic structure of science is based on research and inquiry skills, and the examination of its effects on scientific process skills and 21st century skills. As a matter of fact, it is important to make use of virtual laboratory environments that are compatible with technology, which emerges against conventional teaching methods, in order to create a positive perspective for students' science lesson day by day. On the other hand, the necessity of revealing the effectiveness of virtual laboratory applications, which have gained popularity in science teaching, or determining the advantages and disadvantages, could be a source of determining the opinions on the development and evaluation of the virtual laboratory within the scope of thesis studies. Karagoz Mırcık (2018) argues that students can gain practical skills, reach the desired academic level, and provide more effective learning with virtual laboratory applications. Similarly et al. (2010) point out the effects of virtual laboratories in different areas, when examined from an educational point of view, in terms of improving students' problem-solving skills, learning based on research, and supporting cooperative learning scenarios. Therefore, the desire to see the reflections of virtual laboratories on variables including academic achievement, attitude, motivation and scientific process skills in science teaching is becoming the target point of educators. In this direction, it would be natural to include studies that can reveal the positive or negative effects of virtual laboratories in science education in the determined variables. It is obvious that the existence of thesis studies that pursue the aforementioned purposes is important in terms of using virtual laboratories (De Jong et al., 2013; Kapıcı & Akcay, 2020), which have gained popularity in science education, in the learning and teaching process.

The fact that the thesis studies with virtual laboratory content are carried out with quantitative and mixed research design can be associated with the need for virtual environments to be based on applications and to carry out experimental studies. The aim of measuring the effectiveness of virtual environments that require application on any independent variable may have required it to be carried out with a quantitative pattern. Such studies can support the possible view that aims to reveal any practical activity (Büyüköztürk et al., 2012; Bacanak et al., 2011). On the other hand, it can be deduced that there is insufficient qualitative research in the studies on virtual laboratories, and that depth cannot be achieved in reaching the opinions of virtual laboratories practitioners. Similarly, Arslan et al. (2022) examined technology-integrated studies in education and found that quantitative research method was preferred the most. Likewise, it was determined that the quantitative design was used in the study in which descriptive content analysis of technology-integrated studies

in science education was performed (Namdar & Küçük, 2018). In this direction, although the literature studies do not show a one-to-one overlap with the current synthesis study, they contain parallelism. It was revealed that the thesis studies were carried out on the 5th and 7th grade students at the secondary school level. Focusing on secondary school students in studies suggests the possibility that virtual laboratory applications may become more interesting for secondary school students and that the student group at that level may be more willing. On the other hand, the reason why virtual laboratory environments are preferred in terms of providing students with the opportunity to experiment by trial and error and creating an effective learning environment for individuals who have not completed their concrete period stands out. On the other hand, it comes to mind that it has been decided to work with teachers from different branches, which can be expressed as the first group of practitioners, in order to access field information on the implementation and process of virtual laboratory environments. As another explanation for this situation, the selection of the easily accessible sampling type by the researchers can be given as a reason for studying these groups.

It is obvious that the studies examined within the scope of the research are mostly carried out in electricity and force/motion units, and therefore more orientation is shown to the subject area of physics. Following this, the presence of an orientation to the field of chemistry stands out. At this point, it can be stated that the fields of physics and chemistry are more suitable for simulation experiments than the field of biology. Similarly, Namdar and Küçük (2018) found that the studies in which technology was integrated in science education were mostly focused on the force and movement unit.

In virtual laboratory studies, it has been observed that mostly test or survey/scale data collection tools are used. It is thought that this situation is due to the fact that the thesis research is mostly carried out in a quantitative research design. On the other hand, achievement-oriented measurement of the effectiveness of virtual laboratories on science teaching in general can form the basis for the use of achievement test to a large extent. The fact that scales are used as a data collection tool in the synthesis studies in the field of technology in education prepared in our country in the literature (Arslan et al., 2022; Kıranlı et al., 2021; Namdar & Küçük, 2018) supports the findings of the current study. It is seen that statistical analysis are mostly used in the data analysis of the examined theses. The aim of the studies to measure the effect of virtual laboratory applications on a variable and the studies to be conducted based on quantitative research methodology make it necessary for the analysis to be statistical. On the other hand, in this study, it is seen that qualitative data analysis methods and descriptive analysis methods are less preferred. Less preferred interviews as a data collection tool can provide evidence that the aforementioned qualitative analysis methods are less preferred. It has been concluded that most of the virtual laboratory studies are applied and the application periods are generally between 2-6 weeks and 7-12 weeks. The fact that virtual laboratory applications require a hardware history before the actual use may require a wide period. In addition, it can be an effective factor on the application time in the face of situations where applications require trial and error processes, and its use can take time.

Mostly used applications in the studies were developed by the researcher or applications such as PhET, web-based ready-made simulations, EBA, Crocodile Physics, ChemLab were used. Uses of different virtual lab applications by researchers; The reasons can be listed as the fact that the practitioner has experience, can easily access, is based on the level of application, and preferred applications that do not require cost. It points out that the use of virtual laboratory applications by teachers during science education has disadvantages such as expensive, paid, insufficient teacher training, not being suitable for the level, lack of time, and excess class size (Günlü, 2020). At this point, it would not be wrong to conclude that they chose the appropriate application by aiming to eliminate the disadvantages listed by the teachers.

The results of the research show that virtual laboratory applications have positive effects on participants' academic achievement, scientific process skills, attitude towards the course, and have positive effects on conceptual changes, elimination of misconceptions and concept retention. In addition, it was determined that the virtual laboratory increased the interest and motivation of the participants, and had a positive effect on entrepreneurship, 21st century skills, argumentation, and hypothesis-building skills. Virtual laboratories are beneficial in every aspect of science teaching, on the grounds that they enable learners and instructors to make learning active, more funny, increase student success, and provide an opportunity to practice what they have learned (Aydın, 2018; Wang & Tseng, 2018; Zacharia & Michael, 2016). It is obvious that he occupies an important position in his name. Synthesis studies carried out in the literature are also parallel with our current study, emphasizing that virtual laboratories can be used either alone or in combination with traditional methods, and that learning outcomes can be created. They also reveal that the use of virtual laboratories increases students' motivation and ensures participation in learning (Chan et al., 2021; Triejunita et al., 2021). The fact that it is determined within the framework of the study that it is effective in concept learning makes us think that virtual laboratories will serve as a tool in eliminating misconceptions.

It has been determined that the suggestions presented in the studies prepared on the virtual laboratory can be used

in places where laboratories are insufficient or not available, in order to allow dangerous and difficult experiments to be carried out and used in the learning of abstract and difficult subjects, and to be used for planning teaching, developing activities and curricular arrangements.

CONCLUSION AND RECOMMENDATION

Through theses, it has been proven that virtual laboratories have a positive effect on student success, concept learning, and attitude and play a role in gaining many skills. At this point, it is recommended that educators make effective use of virtual laboratories in the science teaching process and increase their use, especially in low-achieving classrooms. It has been determined that virtual laboratory applications are generally carried out for secondary school students. However, it can be stated that these applications should focus on undergraduate students and teachers. The thesis studies carried out are generally based on quantitative research, but qualitative research is also needed. On the one hand, when it is aimed to reveal the advantages or disadvantages of the practices, on the other hand, it is recommended to carry out qualitative studies when it is considered that action research should be practice oriented. Although virtual laboratories are generally applied in the fields of physics and chemistry, there are not many theses in the field of biology. In this direction, it is recommended to contribute to the literature by carrying out studies on the biology subjects of online laboratory applications. In addition, it is recommended to carry out studies that measure the effect on other skills and acquisitions within the framework of science. Finally, considering benefits of virtual laboratories, it is suggested that teachers should receive training on virtual laboratory practices through in-service training, and prospective teachers through undergraduate education.

Etik Komite Onayı: Araştırma kapsamında bireyden veri toplanmadığı ve deneysel bir uygulama gerçekleştirilmediği için etik kurul izni alınmamıştır.

Çıkar Çatışması: Yazarlar çıkar çatışması beyan etmemişlerdir.

Finansal Destek: Yazarlar finansal destek beyan etmemişlerdir.

Hakem Değerlendirmesi: Dış bağımsız.

Ethics Committee Approval: Since no data was collected from individuals and no experimental application was carried out within the scope of the research, no ethics committee approval was obtained.

Conflict of Interest: The authors declared no conflict of interest.

Financial Support: The authors have not declared any financial support.

Peer-review: Externally peer-reviewed.

REFERENCES

Açıksoy, G., & İşlek, D. (2017). The impact of the virtual laboratory on students' attitudes in a general physics laboratory. *Int J Online Eng, 13*(4), 20–28.

Ahuja, G., Gupta, A., Wardhan, H., & Choppella, V. (2015). Assessing the impact of virtual labs: A case study with the lab on advanced VLSI. *2015 IEEE 15th International Conference on Advanced Learning Technologies*, Taiwan, 290–292.

Akgül, G. D., Gecikli, E., Konan, F., & Konan, E. (2018). Pre-service teachers' opinions about the use of virtual laboratories in science education. *Kesit Academy Journal, 4*(14), 61–74.

Akkağıt, S. F., & Tekin, A. (2012). The effect of simulation-based learning on the success of secondary school students in basic electronics and measurement course. *EFEEFD, 13*(2), 1–12.

Arslan, G. B., Kızılay, E., & Hamalosmanoğlu, M. (2022). Investigation of studies in Turkey on technology integration in education. *AUJEF, 6*(1), 39–55.

Au, W. (2007). High-stakes testing and curricular control: A qualitative metasynthesis. *Educ Res, 36*, 258–267.

Aydın, S. Z. N. (2018). *Use and evaluation of virtual laboratory application in science teaching* (Publication No. 519879) [Master's thesis, Istanbul University]. Ulusal Tez Merkezi.

Bacanak, A., Değirmenci, S., Karamustafaoğlu, S., & Karamustafaoğlu, O. (2011). Science education articles published in e-journals: Method analysis. *J Turk Sci Educ, 8*(1), 119–132.

Bağ, H., & Çalık, M. (2017). Thematic content analysis for argumentation studies at primary education level. *Educ Sci, 42*(190), 281–303.

Bozkurt, E. (2008). *The effect of a virtual laboratory application prepared in physics education on student success*. [Unpublished doctoral dissertation]. Selçuk University.

Bozkurt, E., & Sarıkoç, A. (2008). Can the virtual laboratory replace the traditional laboratory in physics education? *AKEF J, 25*, 89–100.

Brown, J. C. (2017). A metasynthesis of the complementarity of culturally responsive and inquiry-based science education in K-12 settings: Implications for advancing equitable science teaching and learning. *JRST, 54*(9), 1143–1173.

Büyükkara, S. (2011). *The effect of teaching the 8th grade science and technology sound unit with computer simulations and animations on student achievement and attitude* [Unpublished doctoral dissertation]. Selçuk University.

Büyüköztürk, S., Kılıç Çakmak, E., Akgün, O. E., Karadeniz, S., & Demirel, F. (2012). *Scientific research methods*. Pegem Academy. https://depo.pegem.net/9789944919289.pdf

Chan, C., & Fok, W. (2009). Evaluating learning experienc-

es in virtual laboratory training through student perceptions: A case study in electrical and electronic engineering. *Engineering Education, 4*(2), 70–75.

Chan, P., Van Gerven, T., Dubois, J. L., & Bernaerts, K. (2021). Virtual chemical laboratories: A systematic literature review of research, technologies and instructional design. *CAEO, 2*, 100053.

Çalık, M., & Sözbilir, M. (2014). Parameters of content analysis. *Educ Sci, 39*(174), 33–38.

Çalık, M., & Wiyarsi, A. (2021). A systematic review of the research papers on chemistry-focused socio-scientific issues. *J Balt Sci Educ, 20*(3), 360–372.

Çalık, M., Ayas, A., & Ebenezer, J. V. (2005). A review of solution chemistry studies: Insights into students' conceptions. *J Sci Educ Tech, 14*(1), 29–50.

Çinici, A., Özden, M., Akgün, A., Ekici, M., & Yalçın, H. (2013). Comparison of the effects of virtual and traditional laboratory practices on the achievement of 5th grade students in light and sound unit. *BJEF, 8*(2), 92–106.

De Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science, 340*(6130), 305–308.

Deepika, N. M., Bala, M. M., & Kumar, R. (2021). Design and implementation of intelligent virtual laboratory using RASA framework. *Materials Today: Proceedings*.

Dinçer, S. (2018). Content analysis in scientific research: Meta-analysis, meta-synthesis, and descriptive content analysis. *BUEFAD, 7*(1), 176–190.

Duman, M. S., & Avcı, G. (2016). The effect of virtual laboratory applications on student success and permanence of what has been learned. *EUJEF, 18*(1), 13–33.

Earley, M. A. (2014). A synthesis of the literature on research methods education. *Teach High Educ, 19*(3), 242–253.

Ekici, M. (2015). *Science teachers' opinions about virtual laboratory and their level of use from this method* [Master's thesis, Adıyaman University].

El Kharki, K., Berrada, K., & Burgos, D. (2021). Design and implementation of a virtual laboratory for physics subjects in Moroccan universities. *Sustainability, 13*(7), 3711.

Erdan, S. (2014). *The effect of virtual laboratory on learners' academic achievement and perceived learning* [Master's thesis, Eskişehir Osmangazi University]

Erwin, E. J., Brotherson, M. J., & Summers, J. A. (2011). Understanding qualitative metasynthesis: Issues and opportunities in early childhood intervention research. *J Early Interv, 33*(3), 186–200.

Faour, M. A., & Ayoubi, Z. (2018). The effect of using virtual laboratory on grade 10 students' conceptual understanding and their attitudes towards physics *J Educ Sci Environ Health, 4*(1), 54–68.

Gunawan, G., Harjono, A., Hermansyah, H., & Herayanti, L. (2019). Guided inquiry model through virtual laboratory to enhance students' science process skills on heat concept. *Cakrawala Pendidikan, 38*(2), 259–268.

Gunawan, G., Harjono, A., Sahidu, H., & Herayanti, L. (2017). Virtual laboratory to improve students' problem-solving skills on electricity concept. *IPA Indones, 6*(2), 257–264.

Günlü, E. (2020). *Secondary school science teachers' views on the applicability of using virtual labs in science learning* [Unpublished master's thesis, Mersin University].

Hannes, K., & Macaitis, K. (2012). A move to more systematic and transparent approaches in qualitative evidence synthesis. *Qual Res J 12*(4), 402–442.

Hawkins, I., & Phelps, A. J. (2013). Virtual laboratory vs. traditional laboratory: Which is more effective for teaching electrochemistry? *Chem Educ Res Pract, 14*(4), 516–523.

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 J Math Sci Tech Ed, 12*(3), 593–608.

Herga, N. R., Grmek, M. I., & Dinevski, D. (2014). Virtual laboratory as an element of visualization when teaching chemical contents in science class. *TOJET, 13*(4), 157–165.

Hsu, Y. S., & Thomas, R. A. (2002). The impacts of a web-aided instructional simulation on science learning. *Int J Sci Educ, 24*(9), 955–979.

İnce, E., Kirbaslar, F. G., Yolcu, E., Aslan, A. E., Kayacan, Z. C., Alkan Olsson, J., & Yolcu, O. (2014). 3-dimensional and interactive Istanbul University virtual laboratory based on active learning methods. *TOJET, 13*(1), 1–20.

Jensen, N., Von Voigt, G., Nejdl, W., & Olbrich, S. (2004). Development of a virtual laboratory system for science education. *IMEJ, 2*(3), 1–6.

Jeschke, S., Richter, T., & Zorn, E. (2010). Virtual labs in mathematics and natural sciences. *Online Educa Berlin Conference Proceedings*.

Kaba, U. A. (2012). *The effectiveness of virtual laboratory applications as support material in distance science education* [Master's thesis, Anadolu University].

Kapıcı, H. O., Akçay, H., & De Jong, T. (2019). Using hands-on and virtual laboratories alone or together: Which works better for acquiring knowledge and skills? *J Sci Educ Tech, 28*(3), 231–250.

Kapıcı, H. O., Akçay, H., & Çakır, H. (2022). Investigating the effects of different levels of guidance in inquiry-based hands-on and virtual science laboratories. *Int J Sci Educ*, 1–22.

Kapıcı, H. O., Koca, E. E., & Akçay, H. (2018). Effects of writing to learn activities in hands-on and virtual laboratory environments. *The Eurasia Proceedings of Educational and Social Sciences, 9*, 48–51.

Kapıcı, H., & Akçay, H. (2020). Enhancing pre-service sci-

ence teachers' inquiry skills in hands-on and virtual laboratory environments. *Themes in e-Learning, 13*, 21–32.

Kapıcı, H. O., Akçay, H., & De Jong, T. (2020). How do different laboratory environments influence students' attitudes toward science courses and laboratories? *J Res Technol Educ, 52*(4), 534–549.

Karagöz Mircik, O. (2018). *The effects of virtual lab aided 7E teaching model on students' mental models in teaching concepts related to simple electric circuits* [Doctoral dissertation, Karadeniz Technical University].

Karagöz-Mırçık, Ö., & Saka, A. Z. (2016). Evaluation of virtual laboratory supported applications in physics teaching. *J Res Educ Teach, 5*(43), 388–395.

Kıranlı Güngör, S., & Dertli, G. (2021). Analysis of studies on educational technology in higher education institutions. *JCER, 9*(18), 795–830.

Koç Ünal, İ., & Şeker, R. (2020). Investigation of the effect of virtual laboratory applications on student academic achievement: Electric unit. *KEFAD, 21*(1), 504–543.

Kollöffel, B., & De Jong, T. (2013). Conceptual understanding of electrical circuits in secondary vocational engineering education. *JEE, 102*(3), 375–393.

Liao, H., & Hitchcock, J. (2018). Reported credibility techniques in higher education evaluation studies that use qualitative methods. *Eval Program Plan, 68*, 157–165.

Maulidah, S. S., & Prima, E. C. (2018). Using physics education technology as virtual laboratory in learning waves and sounds. *J Sci Learn, 1*(3), 116–121.

Mesutoğlu, C., & Baran, E. (2021). Integration of engineering into K–12 education. *Res Sci Technol, 39*(3), 328–346.

Miles, M. B., & Huberman, A. M. (2016). *Qualitative data analysis* (S. Akbaba Altun & A. Ersoy, Trans.). Pegem Academy.

Moshell, J. M., & Hughes, C. E. (2002). Virtual environments as a tool for academic learning. In *Handbook of virtual environments* (pp. 933–950). CRC Press.

Mutlu, A. (2015). *The effect of guided inquiry based activities in real and virtual laboratory environments on the learning process at the general chemistry level* [Doctoral dissertation, İstanbul University].

Namdar, B., & Küçük, A. (2018). Descriptive content analysis of technology integration studies in science education. *MAKU Eğt*, (48), 355–383.

Nivalainen, V., Asikainen, M. A., Sormunen, K., & Hirvonen, P. E. (2010). Preservice and inservice teachers' challenges in the planning of the practical work. *Journal of Science Teacher Education, 21*(4), 393–409.

Pınar, M. A., & Dönel Akgül, G. (2021). Comparison of the effects of virtual and traditional laboratory practices. *AKUNED, 4*(2), 13–25.

Polat, S., & Ay, O. (2016). Meta-synthesis: A conceptual analysis. *J Qual Res Educ, 4*(2), 52–64.

Pramono, S. E., Prajanti, S. D. W., & Wibawanto, W. (2019). Virtual laboratory for elementary students. *J Phys Conf Ser, 1387*(1), 012113.

Sapriadil, S., Setiawan, A., Suhandi, A., Malik, A., Safitri, D., Lisdiani, S. A. S., & Hermita, N. (2019). Effect of higher order thinking virtual laboratory in electric circuit on students' creative thinking skills. *J Phys Conf Ser, 1204*(1), 012025.

Sarı Ay, Ö., & Yılmaz, S. (2015). Effects of virtual experiments oriented science instruction on students' achievement and attitude. *EEO, 14*(2), 609–620.

Suri, H., & Clarke, D. (2009). Advancements in research synthesis methods. *Rev Educ Res, 79*(1), 395–430.

Tatlı, Z., & Ayas, A. (2010). Virtual laboratory applications in chemistry education. *Procedia Soc Behav Sci, 9*, 938–942.

Tatlı, Z., & Ayas, A. (2011). Virtual chemistry laboratory development process. In *5th International Computer & Instructional Technologies Symposium*.

Tekbıyık, A., & Ercan, O. (2015). Effects of the physical laboratory versus the virtual laboratory. *IJPE, 11*(3), 77–89.

Triejunita, C. N., Putri, A., & Rosmansyah, Y. (2021). A systematic literature review on virtual laboratory for learning. *2021 International Conference on Data and Software Engineering*. Bandung, Indonesia.

Tüysüz, C. (2010). The effect of the virtual laboratory on students' achievement and attitude in chemistry. *Int Online J Educ Sci, 2*(1), 37–53.

Ültay, N., & Çalık, M. (2012). A thematic review of studies into the effectiveness of context-based chemistry curricula. *J Scie Educ Tech, 21*(6), 686–701.

Wang, T. L., & Tseng, Y. K. (2018). The comparative effectiveness of physical, virtual, and virtual-physical manipulatives. *IJSME, 16*(2), 203–219.

Widowati, A., Nurohman, S., & Setyowarno, D. (2017). Development of inquiry-based science virtual laboratory. *Jurnal Pendidikan Matematika dan Sains, 4*(2), 82–89.

Wolf, T. (2009). Assessing student learning in a virtual laboratory environment. *IEEE Transactions on Education, 53*(2), 216–222.

Zacharia, Z. C., & Michael, M. (2016). Using physical and virtual manipulatives to improve primary school students' understanding of electric circuits. In M. Riopel & Z. Smyrnaiou (Eds.), *New developments in science and technology education* (pp. 125–140). Springer.

APPENDIX 1. Studies Examined Within the Scope of Research

T1. Doğan, E. (2024). The effect of virtual laboratory applications on academic achievement, attitude and retention in the subject of density in Year 6 [Master's Thesis].

T2. Tüter, A. (2024). The effect of virtual laboratory applications in physics lessons on student academic achievement and attitude towards the subject [Master's Thesis].

T3. Aydın, H. (2024). Method-activity interaction: lecture-based teaching versus the 5E learning cycle and simple tools versus interactive simulations [Master's Thesis].

T4. Avcı, K. (2024). The effect of using animations on the academic achievement and attitudes towards science of Year 8 secondary school pupils in relation to physical and chemical changes in science lessons [Master's Thesis].

T5. Abdiusta, E. (2024). The effect of virtual laboratory applications used in primary school Year 4 Science lessons on pupils' academic achievement and the retention of learning. [Master's Thesis].

T6. Özeler, E. (2024). The effect of virtual laboratory applications on the teaching of the particulate structure of matter on secondary school pupils' success [Master's Thesis].

T7. Yılmaz, A. (2024). The effect of the 5E method supported by augmented reality and simulation on students' academic achievement, attitudes and motivation: Force and energy unit [Master's Thesis].

T8. Tuna, S. (2023). The effect of virtual laboratory-supported teaching on students' conceptual understanding and attitudes towards electrical circuits [Master's Thesis].

T9. Özhan, B. (2023). Teachers' views on the use of Algodooprogram activities, a simulation software in science education. [Master's Thesis].

T10. İncekara, A. N. (2023). The effect of using simulation methods in electrical circuits on students' science academic achievement and attitudes towards science [Master's Thesis].

T11. Aktaş, E. (2023). The development of animations on photosynthesis and the effect of animation use on student achievement. [Master's Thesis].

T12. Çoban, A. (2023). The investigation of the effects of Arduino-based STEM and algorithm-based simulation in mechanical education. [Doctoral Thesis].

T13. Erkoca, Ö. (2023). Pre-service science teachers' experiences of computersimulation and virtual reality application describing atomsand molecules and their combined effects onrepresentational competence skills [Master's Thesis].

T14. Küçük, M. (2022). The effect of animation-supported audio teaching on the academic achievements of sixth-grade students [Master's Thesis].

T15. Karahan, M. (2022). The effect of simulation-based science education on the academic success of 6th grade students: The unit of systems in our bodies [Master's Thesis].

T16. Keskin, Z. (2022). Investigation of interactive simulation experiences of science teachers and 7th grade students [Master's Thesis].

T17. Baş, K. (2022). The effects of virtual laboratory applications on students' academic achievement and science attitudes in science education [Master's Thesis].

T18. Çatak, O. (2022). The use of conceptual change texts supported by Algodoo software in improving students' misconceptions in the 9th grade work and energy unit [Master's Thesis].

T19. Durmaz, C. (2021). The effects of computer-aided simulation method on the academic achievement, attitudes and misconceptions of 7th grade students in the unit 'Solar System and Beyond'. [Master's Thesis].

T20. Aydın, H. (2021). The effect of animation-supported case study-based science learning environment on academic achievement and motivation [Master's Thesis].

T21. Kapıcı, H. Ö. (2021). The effects of virtual and applied laboratories on secondary school students' concept knowledge, inquiry skills and attitudes [Doctoral Thesis].

T22. Aslan, F. (2021). The effects of GeoGebra applications on academic achievement, misconceptions and retention of learned concepts of pre-service science teachers' on the subject of the projectile motion. [Master's Thesis].

T23. Dinc Bilgin, S. (2021). The effect of 2D and 3D aided modeling based teaching on students' academic achievement and 21st century skills [Master's Thesis].

T24. Canöz, G.M. (2020). Investigate the effect of argumentation based virtual laboratory activities on academic achivement, argumentation levels and entrepreneurship skills [Master's Thesis].

T25. Diyarbekir, G. (2020). Determination of 7th grade students' misconceptions on the force and motion subject based on the ontology and elimination of misconceptions with animation assisted instruction (Unpublished Doctoral Thesis).

T26. Koç Unal, İ. (2019). Investigation of the effects of virtual and real laboratory applications on the academic achievement of 5th grade science course electric unit teaching [Master's Thesis].

T27. Bıçak, F. (2019). The effect of using interactive boards enriched with simulations on academic achievement in science: "6th grade force and motion sample" [Master's Thesis].

APPENDIX 1. Studies Examined Within the Scope of Research (Cont.)

T28. Yıldız, M. (2019). The effect of teaching about buoyancy force withsimulation technique on students achievements [Master's Thesis].

T29. Konak, M. (2019). The effect of the teaching through simulation in the science and technology lessons on the earning the skill of hypothesizing in the lab activities [Master's Thesis].

T30. Bayram, Y. (2019). The effect of simulations supported 5E learning cycle model on seventh grade students' understanding and interest on electric concepts [Master's Thesis].

T31. Karagöz Mırcık, O. (2018). The effects of virtual laboratory assisted 7e instructional model on students' mental models in teaching concepts on simple electric circuits [Doctoral Thesis].

T32. Aydin, S. Z. N. (2018). Use and evaluation of virtual laboratory applications [Master's Thesis].

T33. Sertkaya, O. F. (2018). The effect of 5e model supported by algodoo software in the simple machine unit of 8th grade science lesson [Master's Thesis].

T34. Meral, A. (2018). The application effect of web-based online virtual science and technology laboratory activities to student motivation and success [Master's Thesis].

T35. Duygu, E. (2018). The effect of STEM education on science process skills and STEM awareness in simulation based inquiry learning environment [Master's Thesis].

T36. Aydogdu, S. Y. (2017). The effect of interactive simulation enriched inquiry learning instruction on ninth grade students' achievement in and attitude towards energy [Doctoral Thesis].

T37. Öner, Y. E. (2017). Effect of simulation and animation assisted by 5e model on science success and motivation of teacher candidates [Master's Thesis].

T38. Duman, M. S. (2015). Determination of misconceptions in instruction of states of matter and heat unit to 8th grade students and effects of virtual laboratory applications on the correction of misconceptions students' achievements attitudes and persistence of the learned content [Master's Thesis].

T39. Mutlu, A. (2015). The The effect of guided inquiry based general chemistry activities on learning process in real and virtual environments.[Doctoral Thesis].

T40. Ekici, M. (2015). Science teachers' opinions and utilization levels about the virtual laboratory [Master's Thesis].

T41. Güney, T. (2015). The effect of simulation aided science laboratory applications based on inquiry on science process skill: An example of the force and motion unit [Master's Thesis].

T42. Köklü, N. (2015). The development of animation, simulation and analogy models due to the success of student and being memorable in general physics laboratory [Doctoral Thesis].

T43. Koçer, M. G. (2015). Computer aided in physics education for an optical simulation program of preparation and evaluation [Master's Thesis].

T44. Naseriazar, A. (2015). Effectiveness of different conceptual change techniques enhanced with 5E model in teaching chemical equilibrium [Doctoral Thesis].

T45. Akkagit, S. F. (2014). The effect of the web based education by using simulation and animation onto nineth class students in "electric and magnetism" unit [Master's Thesis].

T46. Küçük, T. (2014). The effect of using simulation method in light unit on students' science achievement and science attitudes [Master's Thesis].

T47. Erdan, S. (2014). The effect of virtual laboratory to learners academic achievement and percieved learning [Master's Thesis].

T48. Kunduz, N. (2013). The effect of teaching with animations and educational games on academic achievement in subject of precipitation titration [Master's Thesis].

T49. Kaba, A. U. (2012). Effectiveness of virtual laboratories as additional material in online science education [Master's Thesis].

T50. Ersoy, F. N. (2012). The effect of computer simulations and conceptual change texts on teaching static electricity [Master's Thesis]

T51. Büyükkara, S. (2011). he effect of teaching unit sound of primary school 8th. grade science and technology course with computer simulations and animations on students? success and attitude [Master's Thesis].

T52. Koyunlu Ünlü, Z. (2011). The effects of combined application of computer simulations and labrotory activities on the students? science achievement and attitudes of towards computer [Master's Thesis].

T53. Tatlı, Z. (2011). Development, application and evaluation of virtual chemistry laboratory experiments for chemichal changes unit at secondary school 9th grade curriculum [Doctoral Thesis].

T54. Guvercin, Z. (2010). Effects of using simulation-aided software in physics lessons on students? academic performance and attitudes and on permanence [Master's Thesis].