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Effectiveness of virtual laboratories on developing expert thinking and decision-making skills among female school students in Palestine

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Abstract

The virtual laboratory is considered one of the latest technologies in the field of education that aims to develop the educational skills of students such 100 hundred school students from a public all-girl primary school in east Gaza were divided into two groups to participate in a quasi-experimental study. Each group completed a particular pre- and post-tests for expert thinking and decision-making skills. The results showed that students in the experimental group were significantly higher than students in the control group in the total mean score of the expert thinking test (27.89 versus 12.47; $p=0.001$, $\eta^2=0.71$). A comparison of the pre-post score for the expert thinking test showed a significant improvement in students' performance ($p=0.001$). The post scores for the decision-making scale showed a significant difference between students in the control group and the experimental group ($p=0.001$). The total mean score of the decision-making scale in the experimental group in the post-scale (82.32±10.87) was significantly higher than the pre-scale score (70.85±9.80) ($p=0.001$). It could be concluded that using virtual laboratory and simulation applications had a positive impact on improving students' scientific knowledge, scientific process, decision-making ability and developing expert thinking skills.

Keywords: virtual laboratories, simulation applications, school students, decision making skills, expert thinking

INTRODUCTION

Science subject has received wide attention and facing great interest and remarkable development as a result of the scientific knowledge explosion. The consolidation of knowledge scientific through the actual application of the concepts is a very important step Toward achieving educational goals. The performance of the laboratory experiment is linked to what educational institutions call for modern trends in education through observation and application so that students can access laws, scientific concepts, and skills (Kristen et al., 2017). Despite the importance of conducting laboratory experiments in a real laboratory, it may be exposed to many challenges that reduce its efficiency and quality, which may make it difficult for each student to conduct the laboratory experiment and repeat it. To acquire the performing skills, which led to a weakness in the performing skills (Brockman et al., 2020).

With the massive evolution in distance education, the learners face some problems regarding developing the skills that help them to overcome contemporary developments, such as expert thinking skills due to the method of teaching, as some teachers refrain from using techniques and educational tools that enhance the level of learners' performance and develop of expert thinking skills. The use of virtual laboratories in science education can provide a safe environment that reduces the occurrence of real laboratory obstacles, achieves educational goals, and develops expert thinking skills (Almuqbil, 2020).

In the twenty-first century, people everywhere benefit from the accessibility of technology and the transmission of information. A new social and economic structure is created as a result of this process, one that

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Contribution to the literature

- This study adds to the limited literature about the importance of employing virtual laboratories in developing expert thinking and decision-making skills for students among primary school students.
- Since this study conducted in virtual laboratories focuses on students, it can bridge the gap in the literature by providing insights on how students might enhance their learning competence, skills of expert thinking and decision-making. Improvements to teaching practices can be made to meet students' needs by understanding the impact of using virtual laboratories and simulation applications in the teaching of chemistry experiments, its impact on students' life skills, and how it can be changed through the implementation of new teaching methods like virtual laboratories.
- This study highlights to see how the virtual laboratory affects students' other life skills when combined with other classroom teaching practices. The data and findings from this paper will be added to an ongoing study into how virtual laboratories might improve student skills and thinking, as well as provide a better knowledge of science topics, particularly for abstract notions.

describes changes in structural transformation, technological advancement, and labor market rivalry. We anticipate being able to internalize the different difficult work domains that deal with information technology and demand expert thinking and communication. People might therefore use the current trends in expert thinking as one of the educational frameworks for the twenty-first century (Syarifah et al., 2019). There are several important factors that affect student decision-making skills such as the absence of decision-making skills learning materials and a lack of learning during the learning process, past experiences, and individual characteristics including age and socioeconomic status (Rahayu et al., 2019).

Based on our experience in teaching science to eighth ninth-grade students, we noticed a low level in the ability to take the appropriate decision to solve the problems they face; therefore, this study highlights the effect of virtual laboratories in providing the learner with the skills of the expert thinking and the decision-making of ninth-grade female students in science subject in a public school in the Gaza Strip in Palestine.

LITERATURE REVIEW

Virtual Laboratory

A virtual laboratory is an interactive practical environment in which students can carry out scientific simulated experiments (Redel-Macías et al., 2016) as well as improve their abilities, skills, and comprehension of science ideas. Several projects have been conducted to demonstrate the importance of employing virtual laboratories in science education. For example, in the study of de la Torre et al. (2015), they showed that the virtual laboratory had a favorable impact on the students' learning. Also, Billah and Widiyatmoko (2018) revealed that the content of the virtual laboratory, which includes theoretical material with graphics, animation, and videos, allow students to learn independently as students favor computer-related topics. Zhao et al. (2019) reported that a virtual laboratory was prepared to supplement the laboratory experiences and make it highly interesting and valuable. In addition, it was reported that virtual laboratory enhances conceptual understanding (Gunawan et al., 2018b, 2019; Lestari & Supahar, 2020; Raman et al., 2022; Zaturrahmi et al., 2020), problem-solving skills (Gunawan et al., 2017), creativity (Gunawan et al., 2018a, 2018c), open up new learning perspectives that cannot be explored in a regular laboratory (Jiménez et al., 2021; Martín-Gutiérrez et al., 2017) and produce learning outcomes that are equivalent to traditional hands-on laboratories (Salmerón-Manzano & Manzano-Agugliaro, 2018; Wästberg et al., 2019).

The enormous benefit of virtual laboratories was noticed when educational activities were hampered due to the widespread of the COVID-19 pandemic (Gamage et al., 2020). During the COVID-19 pandemic, all educational institutions were closed, therefore educators were instructed to transfer from face-to-face education to distance education (Radwan et al., 2022). The teachers educated the theoretical concepts of their curriculum online through technological devices and digital tools. On the other hand, they found it difficult to teach practical lessons and perform the laboratory experiments syllabus. During the COVID-19 pandemic, virtual laboratories provide students with the opportunity to complete planned laboratory experiments (El Kharki et al., 2021; Kapilan et al., 2020; Méndez Ruiz & Valverde Armas, 2022).

In science education, many studies have been conducted on the use of interactive computer simulations (Luthfi et al., 2021). In science education, computer simulations play an important role in improving the quality of teaching, making classes more appealing to students, and assisting them in gaining a deeper understanding of scientific topics (Kamińska et al., 2019) by providing high levels of interaction, active participation, instant feedback, and repeated practices (Lyons, 2012). A study conducted by Sarabando et al. (2016) found that learners who used computer simulations made more progress than those who simply used hands-on experiments. The use of well-designed computer simulations has the potential to increase learners' positive attitudes toward science (Yehya et al., 2019). The use of well-designed computer simulations has the potential to increase learners' positive attitudes toward science. Simulation is a method of designing teaching and e-learning activities that is used in education (Campos et al., 2020). Computer simulations are programs that mimic features of realistic world situations, including mathematical models, and calculate the consequences of various inputs before selecting the appropriate conclusions. They augment genuine laboratory techniques and skills by providing quantitative and hands-on experience for each experiment (Diwakar et al., 2015). In recent decades, simulation software has become increasingly popular as an instructional tool (Costantino et al., 2012). With the advancement of technology and computer languages, simulation has evolved into a sophisticated tool that accurately represents real-world circumstances.

When conducting studies that could involve dangerous substances and potentially dangerous apparatus, a virtual lab is also very helpful. In the system intended to replace real machines with virtual machines on a single host server, virtual lab is also utilized (Ranjan, 2017). One of the most important studies that emphasized the importance and effectiveness of virtual laboratories is Nechypurenko et al. (2019), which declared that experimental chemical tasks, as one of the varieties of experiments that students conduct in chemistry, is an essential component of an effective teaching and educational process and led to the methodological viability of their use in a variety of lesson types, at different points in a lesson, and in extracurricular activities. According to Yusuf and Widyaningsih (2020), adopting e-learning-based virtual laboratories can improve the learning quality and students' metacognitive skills in chemistry experiment courses through lesson study activities, where the students mostly arrive at reasonable and perfect levels. In addition, Romika and Atun (2021) reported that the scale development of the chemistry student virtual laboratory self-efficacy (CSVL-SE) tool has been shown to have strong construct and content validity from 2021. In the study of Bogusevschi et al. (2020), it was confirmed that virtual lab provides students with a great learning experience, as the majority of the students enjoyed learning using the "water cycle in nature" application.

Expert Thinking

According to Reilly (2008), the characteristics of expert thinking are the ability to perceive and reproduce meaningful thoughts in a specific domain; fast performance of procedures; extensive, rich, planned, interconnected, and easily accessible knowledge structures; superior memory and rich repertoires of educational strategies for problem-solving along with appropriate mechanisms for evaluating and applying these strategies. The researchers define expert thinking skills as a set of higher skills that the student must possess, which is (critical thinking and problem solving, problem solving and decision making). It is considered one of the important foundations of contemporary learning and its application in content knowledge and works to increase motivation and improve learning outcomes (Reilly et al., 2019).

In the study of van Winkelen and McDermott (2010) they concluded that multiple expert thinking skills, that supersede the practice domain, are required for facilitating groups. Given the right conditions, a collaborative group environment and a climate of conditionality, novices can develop different perceptual and theoretical lenses with which to interpret experience, and collectively can reproduce similar thinking patterns as that of an expert. This provides some important evidence regarding shared expertise, and the associated cognition, to substantiate the use of reflection or learning circles in certain practice domains.

Expert thinking is considered a great method to enable students to adopt critical thinking in action and start utilizing its processes in their daily life situations. When addressing a problem or issue that requires critical thinking, teachers should verbalize their executive cognitive processes so that students can hear or see them. There is no action that is too minor to be mentioned. Assuming that learners comprehend or know how to carry out an apparently simple set of cognitive tasks is inappropriate because they are beginners. Learners start to develop those thinking abilities by observing how professionals process information (Persky et al., 2019).

Expect novice students to take at least double the time it would take you as an expert to complete the activity (Persky et al., 2019). Critical thinking skills (interpretation, analysis, evaluation, inference, explanation, and self-regulation) are important for teachers and students. While some students and instructors may think that critical thinking skills are fixed, critical thinking can be developed and augmented through a process of attitude alignment, absorption of knowledge, and learning new thinking skills. For students, critical thinking skills are considered very crucial. While some students and teachers might believe that critical thinking skills are unchangeable, critical thinking can be improved and enhanced through a process of attitude alignment, knowledge absorption, and the acquisition of new thinking techniques. Teachers can instill both the desire and the drive for children to start thinking critically by modeling expert thinking and employing scaffolding approaches to help students' critical thinking development (Haritani et al., 2021; Morancho & Rodríguez Mantilla, 2020; Sutiani, 2021). In the study of Winanda and Anwar (2022), the researchers showed that attention to higher-order thinking skills enables students to express their attitudes, feelings, and opinions to be innovative and creative thinkers. As a result, students must improve their understanding and information, train their minds to think critically and learn to communicate effectively in order to survive in the twenty-first century (Caldas et al., 2020; Reyes-Chua et al., 2021).

Decision Making Skills

Decision making is considered one of the most important social training and must be shared with students starting from the beginning. This is because students will always make decisions at any time. Decision making is the process of making choices by determining a decision, acquiring data, and assessing potential solutions. Following a step-by-step decision-making process can promote making more deliberate, meaningful decisions by organizing relevant information and clarifying options. This approach increases the chances that you will select the most favorable alternative possible. In the study of Wang and Ruhe (2007), the authors reported that decision making is one of the social skills and is a tool that can help you members reach goals and help you be more satisfied with the quality of your life. Decision-making in the current study means "the ability of ninth-grade students to reach the most appropriate solutions to solve the problems they face in environmental situations."

In developing decision-making skills there are several indicators that must be developed in this study (understanding the situation, benefiting from the expertise, evaluating assumptions, and reaching sound decision-making). Owaid (2019) recommended the need to adopt modern models and strategies in teaching due to their positive role in improving the education process and decision-making of students. Moreover, in the study of Mettas (2011), it was reported the student's understanding and implementation of decision-making optimization tactics in the field of design and technology are said to be enhanced by the technology fair. Students who are learning to use virtual applications exhibited an increase in decision-making skills is more significant compared to students who learn to use conventional learning (Hamilton et al., 2021).

The study investigated various difficulties with decision-making that primary students had when designing a technological project. The major difficulty identified is that some students struggle with considering a variety of assessment factors when evaluating their potential solutions. There is no doubt that decision-making skills are among the skills necessary for an individual to be able to collect and use information related to community affairs, and to participate effectively in decision-making and solving problems facing society, and there is a need to use modern strategies and techniques to develop these skills, as the current research aims to find the effectiveness of virtual laboratories in developing decision-making skills.

RESEARCH QUESTIONS AND SIGNIFICANCE

Statement of the Problem

Due to the presence of challenges in learning and teaching science experiments in schools, particularly chemistry experiments, some hands-on laboratory experiments were not available for students due to the unavailable of chemical materials or the difficulty to conduct dangerous experiments. Instead, it is important to fill this gap and solve this issue through seeking alternative methods. Virtual laboratories are considered an educational alternative tool to the hands-on experiments being carried out in resource-constrained science laboratories. It was important to understand how students saw these virtual laboratory experiences and how they influenced their decision-making abilities and expert thinking skills in science. The influence of virtual laboratories on students was used to evaluate whether virtual laboratories should continue to be used once all essential resources for doing experiments have been made available, or if virtual laboratories should simply be used as only a tool to fill in during atypical education situations.

Purpose of the Study

During the COVID-19 pandemic, virtual laboratories were required due to distance learning and remote teaching, however, in the future, virtual laboratories could be a viable education approach in place of hands-on laboratories for specific experiments. virtual laboratories may allow students to participate in labs that require specific equipment that a school does not have, or they may be utilized in instances where students are unable to attend a class, such as on rainy days or when they are sick at home. According to certain studies, virtual laboratories, and traditional virtual laboratories both help students understand science laboratory topics as effectively. By assessing the influence of virtual laboratories on the life skills of students such as decision-making abilities and expert thinking skills, data was utilized to assist the decision on whether or not to continue using virtual laboratories besides traditional laboratories.

Research Questions

This study examines the effectiveness of virtual laboratories in developing expert thinking and decision-making skills for 9th grade students in the Gaza Governorate. Specifically, the study attempts to answer the following five questions:

1. What are the skills of expert thinking to be developed using virtual laboratories for 9th grade students?
2. What are the decision-making skills to be developed using virtual laboratories for the 9th grade students?
3. What is the form of virtual laboratories necessary to develop the skills of expert thinking and decision-making among 9th grade students?
4. What is the effectiveness of virtual laboratories in developing the expert thinking skills of 9th grade students?
5. What is the effectiveness of virtual laboratories in developing the decision-making skills of 9th grade students?

Significance of the Study

This study is the first to identify the effectiveness of virtual laboratories in developing expert thinking and decision-making skills for students. Besides, since this study conducted in virtual laboratories focuses on students, it can bridge the gap in the literature by providing insights on how students might enhance their learning competence, skills of expert thinking and decision-making. Improvements to teaching practices can be made to meet students' needs by understanding the impact of using virtual laboratories and simulation applications in the teaching of chemistry experiments, its impact on students' life skills, and how it can be changed through the implementation of new teaching methods like virtual laboratories. This study can also be performed to see how the virtual laboratory affects students' other life skills when combined with other classroom teaching practices. While virtual labs are useful in emergency situations, they are not always necessary. Science teachers will return to traditional laboratories once chemicals, materials, and equipment are available. However, virtual laboratories may be a useful alternative when equipment or supplies are unavailable owing to space or budget constraints, or they may give a superior learning opportunity for specific content concepts. The potential value of using virtual labs in the future should be weighed against how virtual lab use affects student skills and thinking about science issues. The data and findings from this paper will be added to an ongoing study into how virtual laboratories might improve student skills and thinking, as well as provide a better knowledge of science topics, particularly for abstract notions.

METHODS

Design

A quasi-experimental study with a pre-/post-test design was applied on the study groups (control and experimental groups). This quasi-experimental study was conducted in three phases; a pre-intervention phase where the decision-making scale and the expert thinking test were administered online to the students; an intervention phase where virtual laboratories and simulation applications were employed in science education for the experimental group; and a post-intervention phase where decision-making scale and the expert thinking test were used to gather the required data.

Participants

The current study was conducted in the second semester of 2022/2021, on the 9th grade students in Al-Nasra girls' primary schools in the directorate of East Gaza. The study sample consisted of 100 female students whose ages are between 14-15 years old. The control group consisted of 45 students who learned experiments in chemistry lessons in the traditional laboratory without using virtual laboratories or simulation programs. Experiments that the students could not conduct in the traditional laboratory due to their dangerous effects or unavailable of chemical materials, were only theoretically taught without the use of any simulation programs. The experimental group consisted of 55 students who learned all chemical experiments using traditional laboratories as well as virtual laboratories and simulation applications. Experiments that the students could not conduct in the traditional laboratory due to their harmful effects or unavailable of chemical materials to tools, were theoretically and practically taught using virtual laboratories and simulation applications. All participants had no previous experience with the usage of using virtual laboratories and simulation applications in science learning.

Study Instrument

This study used two instruments: the expert thinking skills test, and the decision-making scale, as follows:

Decision-making scale

This scale was prepared in its initial form, which included 32 items. It was presented to a group of reviewers and specialists to express their opinions and observations about the scale. After that, the scale was modified based on the comments and amendments of the reviewers and specialists, which contributed to improving the quality of the scale until the scale became ready for exploratory application.

Before conducting the scale, a pilot study was carried out to determine the feasibility of the study, clarify misleading sentences, determine weaknesses in the questions, and verify the validity and reliability of the scale. The sample size of the pilot study consisted of 30 female students outside the study sample. We verified the validity and reliability of the instruments, as follows:

1. The Pearson's correlation coefficient *r* of the scores of students' responses to an item with their total scores was calculated to assess the construct validity of the instruments used in our study. The results showed that the Pearson correlation coefficients for all items ranged between (0.917-0.494), indicating acceptable validity.
2. Cronbach's alpha and split-half reliability tests were used to assess the reliability or internal consistency of the scale. The half-test reliability coefficient and alpha Cronbach's coefficient were found 0.86 and 0.91, respectively, indicating high internal consistency of the scale.

After the complete review and pilot stage, the decision-making scale has become in its final form of 21 items distributed on four domains: understanding the situation or problem; evaluating the assumptions available to make the appropriate decision; take advantage of experienced people in decision-making; and making decisions.

Expert thinking test

The test was prepared in its initial form, which consisted of 35 items that were presented to a group of specialists, experienced teachers, and supervisors to review the test items and the extent to which the questions represent the skills of expert thinking. Then the test was modified according to their comments. Before applying the test, a pilot study was conducted to determine clarify misleading questions, determine misunderstandings in the choices, and verify the validity and reliability of the test. The sample size of the pilot study consisted of 30 female students outside the study sample. We verified the validity and reliability of the test, as follows:

1. The Pearson correlation coefficients were calculated to assess the construct validity of the scale and whether each item was correlated with its subscale. Pearson's correlation coefficients were evaluated using the guidelines by Evans (correlation levels: negligible=0.00-0.19, weak=0.20-0.39, moderate=0.40-0.59, strong=0.60-0.79, very strong=0.80-1.00). The results showed that the values of Pearson correlation coefficients ranged between (0.917-0.494), which indicates the internal consistency of the test.
2. A split-half reliability test was applied to assess the reliability or internal consistency of the test. The half-test reliability coefficient was found 0.715 indicating high internal consistency of the scale.
3. The difficulty coefficient was calculated for each of the test items. The coefficients of difficulty ranged from 0.22 to 0.91, and the items with a difficulty coefficient higher than 0.80 were excluded. The difficulty coefficient was calculated after deleting the questions and the difficulty coefficients ranged between 0.22-0.80, while the average total difficulty coefficient was 0.57, which are acceptable values.
4. The discrimination coefficient was calculated for each of the items, and it was found that all the discrimination coefficients for the items ranged between 0.30-0.70, while the average overall discrimination coefficient was 0.42. The discrimination coefficient is accepted if it is greater than 0.20.

Based on the results of the reviewing process, the expert thinking test has become in its final form of 30 items distributed on three domains: deduction; critical thinking; and problem-solving

Procedural Steps

The current study aimed to investigate the effectiveness of using the virtual lab in developing the skill of expert thinking and decision-making according to the implementation of the general design steps (ADDIE), which included five stages: analyze, design, develop, implement and evaluation (**Figure 1**).

Analysis

At this stage, the tasks and the characteristics of participants were determined as follows:

1. The available resources of the educational environment were determined, as the target school is considered a suitable environment for implementing this study and it contains a computer lab prepared for using a virtual laboratory in science lessons. In addition, the virtual laboratory and simulation programs in chemistry were downloaded on the personal devices of the students to allow them to be used at home.
2. The characteristics of the study participants were determined, which is a sample of the 9th grade students who possess the basic skills to use computer applications and desire to learn through simulation.
3. **Content analysis:** The content of the fourth unit (elements and chemical reactions) was analyzed from the science book of the ninth grade. This unit consists of four lessons: modern periodic table, chemical bonds and Lewis representation, types of chemical reactions, and Redox reactions.

Design

A set of simulation programs and applications in designing the experiments was used by the students based on the supervision of the teacher. These five applications were: *Pro Chemical Bonding* (https://apps.apple.com/il/app/pro-chemical-bonding/id1505101742), *Science School Lab Experiment* (https://apps.apple.com/il/app/science-school-lab-

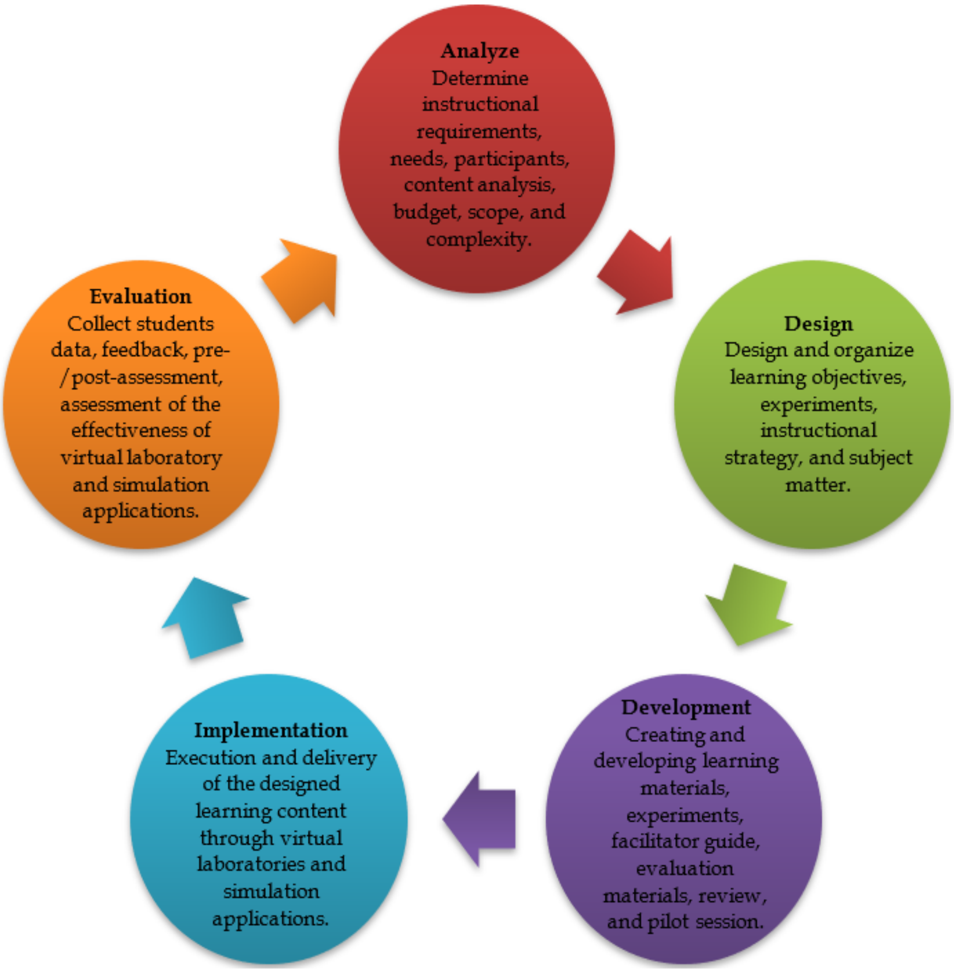

Figure 1. ADDIE model of the present study (Source: Authors' own elaboration)

experiment/id1534857344), *Chemistry* (https://apps.apple.com/il/app/chemistry/id493558583), *Science Lab Experiment & Trick* (https://apps.apple.com/il/app/science-lab-experiment-trick/id1364481404), and *High School Science Experiment* (https://apps.apple.com/il/app/high-school-science-experiment/id1397166125).

Development

The virtual experiments contained in the educational unit were designed using simulation programs and applications in chemistry. Due to the multiplicity of topics of chemical experiments, more than one simulation application was used in proportion to the nature of each experiment. Then the experiments were presented to a group of specialists in the field of technology and science to express their comments. Their recommendations were taken into consideration to output the experience as required to achieve the objectives of learning.

Implementation

This process took three months, with three meetings per week, as follows:

1. The students were divided into two groups: control and experimental groups. The control group consisted of 45 students, and the unit's content was taught in the traditional method. The teacher explains the lessons and performs chemical experiments in a real laboratory. The experiments that cannot be carried out due to the lack of materials or their danger are explained in a traditional method (indoctrination). The experimental group consisted of 55 students, and the content of the unit was taught using virtual laboratories and simulation applications besides using a real laboratory.
2. During the pre-application period, a pre-test design was conducted on students, as they responded to the study instruments before using virtual laboratory and simulation programs in the teaching of experiments. We showed the results of the analysis demonstrating the homogeneity and equivalence of the two groups.
3. Training the students on how to employ virtual laboratory programs (crocodiles) and simulation applications in the conduct of the experiments. The availability of mobile phones for the students, a computer laboratory in the school and an LCD display device are considered important factors that helped teachers and students move forward in the implementation stage. Teachers used

Table 1. The main expert thinking skills included in the target unit

Skills	Definition
Deduction	Ability of students to reach a conclusion by processing the available information or facts according to specific logical procedures.
Critical thinking	Ability of students to analyze knowledge as well as distinguish between hypotheses & instructions, facts, & opinions in a logical method for the chemical laws contained in the unit of chemical reactions & elements.
Problem-solving	Ability of students to analyze, think, & derive alternatives or hypotheses that help solve the problem. In this study, using of problem-solving was achieved by testing validity of hypotheses contained in the target unit.

Table 2. Sub-skills related to decision making skill

Skills	Definition
Understanding the situation or problem	Students make the decision based on understanding the topic of the problem, analyzing the elements of the situation or problem, building decisions according to the circumstances, controlling emotions and minimizing negativity, and making decisions after confirming the results.
Take advantage of experienced people	The ability of students to participate with others in making decisions and evaluating their opinions in verifying decision-making. In addition, ability of students to collect information about the situation before deciding and generate many alternatives for decision-making.
Evaluate assumptions to make an appropriate decision	The student determines the available alternatives to the situation, anticipates the results of each alternative, and decides after confirming the information related to the topic, excluding the impossible alternatives, with possibility of determining advantages and disadvantages of each alternative decision.
Make the right decision	The ability of students to choose the appropriate time to decide and make decisions related to the academic future. Also, the ability to predicting the results before making the right decision and developing an alternative plan to take new decisions.

several educational strategies appropriate to the nature of the experiment, including a problem-solving strategy, participatory learning strategy, and demonstration strategy.

Evaluation

During the post-application period, a post-test design was conducted on students, as they responded to the study instruments after using virtual laboratory and simulation programs in the teaching of experiments.

STATISTICAL ANALYSIS

The statistical analysis of the results of the research was carried out with IBM SPSS (statistics package for social sciences) statistics 22. All data in the study instruments were carefully checked for missing values in the scale and test. The first step of the analysis processes constituted the normality tests of the data. Kolmogorov-Smirnov and Shapiro-Wilk tests were performed to assess the normality of data distributions. The analysis showed that data exhibited normal distribution and were homogeneous.

Questionnaire results were separated into each domain and tested for both validity and reliability. Pearson correlation test was used to test the validity by evaluating the results using the critical value table of the Pearson correlation coefficient. The reliability of the scale was measured using Cronbach's alpha. The coefficients were estimated, considering results above 0.70 as acceptable. The internal consistency of the scale was analyzed using a split-half reliability coefficient. Acceptable correlation coefficients should be more than 0.30.

Also, descriptive statistics consisting of the mean, standard deviation, and percentage were analyzed. The differences in pre- and post-tests for each group was evaluated using paired t-test. An independent sample t-test was used to identify significant differences in pre- and post-tests scores for each group. To determine the magnitude of differences between groups, eta squared (η^2) was reported as a measure of effect size. Effect sizes were reported as either small (η^2=0.01), medium (η^2=0.06), or large (η^2=0.14). A p-value less than 0.05 was considered statistically significant.

RESULTS

The overall results indicated that the application virtual laboratories and simulation applications in science education positively influenced students' knowledge and skills as well as the application of skills into practice in their life.

To answer the first question: What are the expert thinking skills to be developed using virtual laboratories for ninth grade students?

In order to answer this question, previous relevant studies (Persky et al., 2019; Winanda & Anwar, 2022) and the content of the target unit were analyzed to determine the expert thinking skills. The main expert skills included in the target unit of the science curriculum are presented in **Table 1**.

To answer the second question: What are the decision-making skills to be developed using virtual laboratories for ninth grade students?

The decision-making skills (**Table 2**) were determined after reviewing previous studies such as Owaid (2019), Rahayu et al. (2019), Wang and Ruhe (2007).

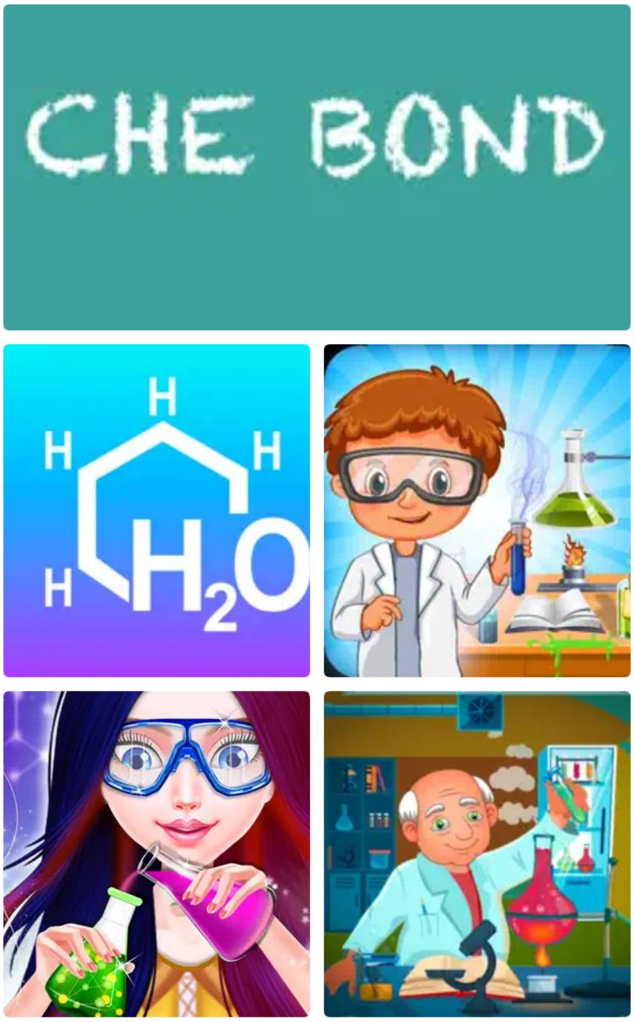

Figure 2. Screenshots from the home pages of the selected applications used by students in the current study

To answer the third question: What is the image of the virtual laboratories necessary to develop the skills of expert thinking and decision-making?

It is a set of applications used by researchers in simulating a chemistry laboratory, where different virtual laboratories were used to cover all various experiments in the target unit (**Figure 2**). In this unit, there are 22 experiments divided into 10 topics, as follows:

1. Periodicity of properties of the elements.
2. Periodic classification of the elements.
3. Chemical bonds.
4. Properties of ionic and covalent compounds.
5. Type of chemical reactions.
6. Burning magnesium.
7. Decomposition of hydrogen peroxide.
8. Single replacement reactions (eg. Zn with HCl, Cu with $AgNO_3$, Al with Fe_2O_3).
9. Double replacement reactions (eg. NaOH with HCl, NaOH with $CuCl_2$, $NaHCO_3$ with CH_3COOH).
10. Oxidation-reduction reactions (C with O_2, Mg with HCl, Ca with O_2).

These applications give students the opportunity to conduct experiments and chemical reactions easily, excitingly, and safely. It can be used on their personal phones or display the experiment on a display screen inside the traditional classroom. Through these applications, chemical materials can be added to the glassware and equipment, and the experiment can be prepared according to the required quantities. Moreover, students can achieve accurate simulation of experiments when mixing materials, with the ability to create tables, figures, and graphs to analyze the results. Also, these applications are equipped with lessons and models for pre-prepared experiments that can be modified, and chemical equations are provided with more than one formula. Some applications can give the chemical and physical properties of elements and allows viewing chemical reactions with each other safely.

For the fourth question: What is the effectiveness of virtual labs in developing expert thinking skills for ninth grade students?

To answer the question, we hypothesized two hypothesis:

1. **H1:** No significant differences between the mean scores of the control and experimental group in the expert thinking test. The results showed that students in experimental group were significantly higher than students in the control group in the total mean score of the expert thinking test (27.89 versus 12.47; $p=0.001$, $\eta^2=0.71$) (**Table 3**).
2. **H2:** There is no significant difference among pre- and post-test scores of students' expert thinking skills test in the experimental group. **Table 4** shows the result of the comparison of the mean of the pre- and post-test of students in the

Table 3. Difference between the experimental and control groups in the expert thinking skills test

Domain	Group (E^a/C^b)	n	Mean	Standard deviation	t	p-value*
Deduction	E	55	7.41	1.24	4.19	0.043
	C	45	3.22	1.59		
Critical thinking	E	55	11.16	1.51	19.84	0.001
	C	45	5.22	2.56		
Problem-solving	E	55	9.31	1.03	31.08	0.001
	C	45	4.02	2.34		
Total	E	55	27.89	3.37	15.67	0.001
	C	45	12.47	5.55		

Table 4. Comparison of the mean of pre- and post-test of students in the experimental group (n=55)

Domain	Group	n	Mean	Standard deviation	t	p-value*
Deduction	Pre-test	55	2.52	1.31	20.72	0.001
	Post-test	55	7.41	1.24		
Critical thinking	Pre-test	55	4.64	1.65	23.89	0.001
	Post-test	55	11.16	1.51		
Problem-solving	Pre-test	55	3.76	1.70	21.28	0.001
	Post-test	55	9.31	1.03		
Total	Pre-test	55	10.93	3.41	28.47	0.001
	Post-test	55	27.89	3.37		

Note. *p-value was calculated using paired sample t-test for paired samples

Table 5. Difference between the experimental and control in the post-application of the decision-making scale

Domain	Group (E[a]/C[b])	n	Mean	Standard deviation	t	p-value*
Understanding the problem	E [a]	55	24.64	3.98	12.18	0.001
	C [b]	45	19.58	6.45		
Take advantage of experienced people	E	55	16.09	2.67	17.71	0.001
	C	45	14.09	4.56		
Evaluate assumptions to make an appropriate decision	E	55	20.24	3.36	12.64	0.001
	C	45	16.53	5.12		
Make the right decision	E	55	21.36	3.00	38.60	0.001
	C	45	16.78	6.00		
Total	E	55	82.33	10.87	29.69	0.001
	C	45	66.98	20.63		

Note. *p-value was calculated using independent sample t-test, statistically significant at $p<0.05$; [a]Experimental group; & [b]Control group

Table 6. Comparison of the mean scores of pre- and post-scale for decision making skills in the experimental group (n=55)

Domain	Group	n	Mean	Standard deviation	t	p-value*
Understanding the problem	Pre-scale	55	19.65	4.40	6.00	0.001
	Post-scale	55	24.63	3.98		
Take advantage of experienced people	Pre-scale	55	14.63	3.28	2.57	0.013
	Post-scale	55	16.09	2.67		
Evaluate assumptions to make an appropriate decision	Pre-scale	55	18.10	2.90	3.37	0.001
	Post-scale	55	20.23	3.35		
Make the right decision	Pre-scale	55	18.45	4.57	3.81	0.001
	Post-scale	55	21.36	3.00		
Total	Pre-scale	55	70.85	9.80	5.68	0.001
	Post-scale	55	82.32	10.87		

Note. *p-value was calculated using paired sample t-test for paired samples

experimental group. Paired-sample t-test results showed a significant difference between the mean scores of the students in pre-test (10.93±3.41) and post-test (27.89±3.37) (p=0.001). The difference between the pre- and post-test was 16.96, which was really different. It means that before and after this study the virtual laboratories have a great effect on expert thinking skills of the students. In addition, the Black modified gain ratio was calculated to measure the effectiveness of virtual laboratories in developing expert thinking skills.

For the fifth question: What is the effectiveness of the virtual laboratories in developing the decision-making skills of the ninth grade students?

To answer the question, we hypothesized two hypothesis:

1. **H1:** No significant differences between the mean scores of the control and experimental groups in the post application of the decision-making scale. The results revealed that the difference in the mean scores of decision-making scale for control group and experimental group was significant (p=0.001; η^2=0.90). The mean scores of students who used virtual laboratory and simulation applications in their education (82.33±10.87) were higher than students who studied in traditional method (66.98±20.63) (**Table 5**).
2. **H2:** No significant difference among pre- and post-test scores of students' decision-making scale in the experimental group. The results showed that total mean score of decision-making scale in experimental group in the post-scale (27.89±3.37) was significantly higher than the pre-scale score (10.93±3.41) (p=0.001). Post-test score of all expert thinking skills was better than the post-test score by 9.24% (95% CI: 8.2-10.3%) (**Table 6**).

The results showed that the total mean score of decision making skills in the experimental group in the post-scale (82.32±10.87) was significantly higher than the pre-scale score (70.85±9.80) ($p=0.001$). The difference between the pre- and post-test was 11.47, which was really different. It means that before and after this study the virtual laboratories have a great effect on all decision making skills of the students in this group.

DISCUSSION

This study aims to identify the effectiveness of virtual laboratories as an educational tool in developing expert thinking and decision-making skills for 9th grade students. In this study, a constructed virtual laboratory and simulation applications were used to educate the chemistry lessons. Students were previously given a pre-test to determine their initial expert thinking and decision-making skills. At the end of the study, a post-test was conducted to determine the influence of the virtual laboratory on the skills of expert thinking and decision-making of the students. Pre- to post-test enhancements in score of students improved their ability to build explanations that incorporated high level ideas of chemical reactions and refined partial and alternative ideas for concepts of oxidation, reduction, chemical bonds, and element periodicity, as evidenced by their test scores.

During the virtual laboratory, students were guided to use balance, graduated cylinder, flasks, and pipette to control the volume of the acid and base chemicals and feel the effect of the concentration on the access to the end point of the titration by controlling the consumed volume through the valve. The obtained results suggest that students were able to add normative ideas as well as enhance alternative ideas about a specific reaction and the relationship between elements and metals in the reactivity series. Virtual science laboratories help students to develop sophisticated scientific explanations by linking molecular-level visualizations to observable results (Alneyadi, 2019; Chiu et al., 2015; Jordá, 2013).

This study reveals the importance of using virtual laboratory and simulation applications in improving the knowledge and learning of science experiments. Also, virtual laboratory enhance a deep understanding of science experiments. The results indicate the positive impact of using the virtual laboratory on learning students and demonstrate that there is a need for the virtual laboratory in the primary schools in Palestine. Virtual laboratories could improve the learning environment and provide students with more clear information. Students who used the virtual laboratories were able to understand the notion of experiments, as well as their goals and results. This was inferred from the results of the post-test for the students who used virtual laboratory during their education as compared to their counterparts who learned in a traditional environment.

The results showed that students who employ virtual laboratory were significantly higher in the score of the expert thinking test as compared to students who learnt in a conventional environment. This result due to the fact that experiments using virtual labs give students the opportunity to deduct precise information, and critical thinking about the problem, as well as hypothesize and prove it in problem-solving (Case, 2022). The experiments are visualized in a two-dimensional simulated laboratory that is colorful and engaging and receives the appropriate equipment in the virtual laboratory (measurement tools, microscope, magnet, electromagnetic tools, etc.). Also, students can manipulate the parameters of the experiments or use virtual measurement devices. In the virtual laboratory, the experiments are visualized in a two-dimensional simulated laboratory that is colorful and attractive and students can receive the appropriate equipment (measurement tools, Bunsen burners, microscope, flasks, chemical materials, etc.).

These results agree with the results reported in the study of Gunawan et al. (2017). They reported that the usage of virtual laboratories in science education has a positive impact on problem-solving skills. Also, El Kharki et al. (2021) reported that the virtual laboratory is beneficial for allowing students to learn by doing and improve thinking abilities. Another study found that using a project-based learning model with virtual media can increase students' creativity (Gunawan et al., 2018a). The usage of virtual laboratories in the classroom has also been shown to increase science skills of students, as well as their critical thinking disposition (Reeves & Crippen, 2021).

There are many reasons standing behind the improvement in the performance in the expert thinking post-test for students who used simulation applications and virtual laboratories such as provides students with tools and visualizations that encourage them to participate and collaborate in class as well as assists them in making connections between theoretical and practical parts (Marks & Thomas, 2021). Also, it is considered as an alternative option for schools that are unable to construct labs or provide instruments and equipment (Coleman & Smith, 2019). Moreover, students can obtain real data from remotely operated instruments and investigate it using simulated instruments, such as the virtual titration, which uses precise quantities of chemicals instead of actual chemicals and materials (Rolfe & Adukwu, 2021). In addition, the recent studies found an increase of concept mastery of science lessons and explore visualize abstract concepts after learning using virtual laboratory in science education (Gunawan et al., 2017).

According to experts and educational supervisors, using virtual laboratories in science education improves students' academic achievements and performance because it allows them to build and create novel knowledge, internalize information, improve understand of scientific concepts, motivate and guide students, self-evaluation based on the registered data, simulate dangerous and/or expensive experiments, minimize the time required for the learning process (Almuqbil, 2020; Brockman et al., 2020; Coleman & Smith, 2019; Potkonjak et al., 2016; Raman et al., 2022; Serrano-Perez et al., 2021). All mentioned above factors help students to deeply understand, recover and remember the information of the aimed experiments, therefore, their score was high, and their academic performance was changed to the best level when compared to the pre-period study (Marks & Thomas, 2021; Triejunita et al., 2021).

The results clearly showed that students significantly increased their ability in making decisions. It means that before and after this study the virtual laboratories have a great effect on all decision making skills of the students. Students make decisions by evaluating data collected based on their senses and applying a cognitive process to choose between at least two options within certain circumstances. This results attributes to the fact that, in virtual environments, the cognitive processes get more complex and challenging as the number of alternatives increases. Science education helps students develop decision-making skills, particularly when using active learning strategies such as adopting virtual laboratories and simulation applications in education. This finding can be explained by the fact that simulation application and virtual laboratories are considered to be useful tools for motivating students to learn in a realistic simulated environment without causing any danger. Students engage in the learning process to develop life skills, including decision-making skills, using a well-plan curriculum. Theoretical learning based on simulation apps and virtual laboratories can also help to improve practical comprehension and increase confidence, therefore, students' decision-making skills in everyday scenarios improved as their learning confidence grew and they learned how to learn in a virtual environment.

Overall, the study found a number of important features of science education through simulation techniques. To begin with, the results show that using simulation as an instructional tool definitely promotes the goals of experiential learning. As a result, students learn how to acquire skills by going through a process, evaluating their knowledge, and applying what they've learned from the simulation experience. This method supports the theory of Lave and Wenger (1991), which confirmed that the learning of students becomes effective when a specific application is presented in a contextual method. The results revealed that the educational experience was linked to increased self-confidence and decision-making skills as a result of the use of simulation programs and virtual laboratories in education. Moreover, students have a great opportunity to learn the steps of decision making and gain experience through practice, therefore, an enhancement in decision-making skill was observed among them. Making decisions is a life skill that helps students grow and involves various factors. Simulation apps assist students in integrating topic knowledge such as events, facts, visuals, and fiction, with real-life circumstances in order to enhance decision-making skills and their teachers encourage each student to make sensible decisions throughout this stage. Finally, some chemistry lessons contain abstract concepts, therefore students struggle to visualize the events and hence understand and memorize them. It is important to apply virtual laboratories and simulation applications that concretizes abstract concepts in order to improve academic achievement of students in science subject.

CONCLUSION

It could be concluded that using virtual laboratory and simulation applications had a positive impact on improving students' scientific knowledge, scientific process, decision-making ability and developing expert thinking skills. The two classes of students have differing increases in decision-making and expert thinking skills. Students can use virtual laboratory to identify and define problems, as well as set goals and objectives. This demonstrates that using virtual labs to teach science improves students' abilities to solve science problems, make good decisions, and use higher-order thinking skills. When the study results are evaluated in order to get better results from virtual laboratories in science education, it is suggested that students should be given adequate time to conduct an experiment they enjoy on their own and/or to design and conduct different experiments. Furthermore, because virtual laboratories serve as a link between subjects and real-world situations, it is thought that a suitable teaching approach and strategy should be used to cover theoretical material.

Limitations

Limitations of this study include the non-representativeness of our sample, which consisted of only female students aged between 14 and 15 years. This may limit the generalizability of our findings to a wider population. Future work could evaluate the effectiveness of a virtual laboratory for males and females students at different ages in different schools. Also, the duration of applied the current study on students was slightly short. Results may somewhat change when the duration is longer, which means that students' interest and curiosity may be reduced; Thus, this study indicates that the period could be longer. Also, this study highlighted on the effectiveness of virtual laboratories in developing expert thinking and decision-making skills. Future work could focus on different extracurricular contents and support education through adopting virtual applications and simulation programs in science education to support 21st century skills.

Author contributions: RA, EH, & ER: conception and design of the manuscript; **RA:** analyzing the data, writing the results and discussion, editing the paper, and improving the study; **EH:** revising research drafts, writing the introduction and results, verifying references, and following up on other research activities; & **ER:** reviewing the literature, referencing, collecting data, writing the discussion, and following up on submissions. All authors have agreed with the results and conclusions.

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