International Journal of Educational Research Review

An Experimental Study on Measuring the Impact of Using Virtual Laboratories in Developing Some Metacognition Skills (Planning, Monitoring, and Control) in the Subject of Physics

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Article History:
Received 02.08.2023
Received in revised form 13.10.2023
Accepted
Available online 15.10.2023

The aim of this research is to investigate the impact of using virtual laboratories in developing some Metacognition skills in the subject of physics among third-grade female students. The research adopted a quasi-experimental design, with a sample of 30 students evenly divided between the control and experimental groups, with 15 students in each group. To achieve the research objectives, the researcher designed a scale for Metacognition skills. The results revealed statistically significant differences between the average scores of the experimental group and the control group in some Metacognition skills (planning, monitoring, and control) in the post-application phase in favor of the experimental group, which studied using virtual laboratories. Furthermore, the results indicated a significant effect size of using virtual laboratories in developing Metacognition skills among third-grade female students in Jeddah. Based on the findings, the research recommends the utilization of virtual laboratory technology in teaching physics and the organization of training courses for physics teachers.

Keywords: Virtual laboratories, metacognition skills, physics education; quasi-experimental design

INTRODUCTION

Our current era is witnessing a tremendous technological revolution that has profoundly impacted all aspects of life, including education, which aims to transmit knowledge and wisdom from one generation to another. As educational institutions are increasingly embracing online learning methodologies, educators and students have discovered the exceptional significance of digital learning tools, which have played a significant role in fundamentally transforming our cultural experience during critical times. This transformation has been achieved through accessing modern technology, enhancing productivity, fostering collaboration, and nurturing creativity (Tayan, 2020).

The use of technology in its various forms serves as a means to efficiently transmit knowledge to learners, reducing time and effort while maximizing the benefits derived. This approach to education embraces modern communication mechanisms, encompassing computers, networks, and diverse multimedia tools such as audiovisual elements, graphics, search functionalities, electronic libraries, as well as internet gateways. These resources can be effectively utilized both in remote learning environments and within traditional classroom settings (Al-Moussa, 2016).

Hence, educational processes have witnessed rapid strides in the utilization of technology and its applications within the teaching and learning domain. One of the most significant educational transformations in the field of applied sciences has been the integration of virtual laboratories, which have gained widespread popularity in advanced nations in recent years due to their unique ability to bridge the gap between theory and application (Albadri, 2016).

The researcher believes that providing learners with the opportunity to experiment and critically think about their actions in problem-solving and fostering creativity empowers them to become conscious learners who are aware of the solutions to the tasks they undertake, rather than mere recipients of instructions. This approach aligns with the 21st-century skills that the Saudi Ministry of Education strives to achieve in the educational process.

Furthermore, Migdadi and Al-zou'bi (2020) emphasize the importance of individuals' awareness of their cognitive processes and their ability to control and regulate them while solving problems. This leads to improved performance and greater goal attainment, surpassing mere thinking and delving into what is beyond cognitive thinking known as metacognition. The term "Metacognition" emerged in the 1970s in the research of Flavell, which focused on understanding the learner's self-awareness as a learner and their capacity

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for planning, monitoring, and evaluating their own learning. Metacognition is defined as an individual's knowledge of their cognitive processes, their outcomes, and their relation to that knowledge. It has received substantial theoretical and applied attention as it represents one of the highest levels of thinking, wherein individuals engage in continuous planning and monitoring of their thinking processes (Sagirli, 2016).

Moreover, the researcher believes that the subject of physics is rich in educational situations, cognitive skills, and practical abilities that, in turn, contribute to the development of critical thinking skills and metacognitive thinking skills, catering to the cognitive and practical needs of learners. Accordingly, the current research aims to contribute to the effective utilization of virtual laboratories in enhancing metacognitive thinking skills in the field of physics.

Problem statement

Virtual laboratories are considered one of the most important modern technological tools used in science education. They aim to replicate the real laboratory environment through digital systems that simulate and complement authentic laboratories. Students are able to conduct scientific experiments in a stimulating and flexible environment that fosters innovation and creativity, thereby acquiring comprehensive scientific experience (Tibola et al., 2019).

Numerous studies have indicated that metacognitive thinking skills are complex mental abilities and crucial components in information processing. They involve tasks that direct and guide thinking activities towards solving specific problems, relying on an individual's cognitive resources or abilities to address the cognitive demands of the task (Alimat, 2018). Moreover, Santos and Prudente (2022) emphasize the significance of virtual laboratories in conducting hazardous and intricate experiments, presenting them in an innovative format that simulates real-life scenarios without any physical risks or costs.

Based on the aforementioned, the distinctive features of virtual laboratories in enhancing the efficiency of the educational process become evident. Furthermore, through the researcher's experience in teaching physics at the secondary level and transitioning between multiple schools, she observed a deficiency in some of the tools used for conducting experiments in general. Additionally, certain physics experiments require special conditions that may not be readily available in some schools. The researcher also noticed that the development of metacognitive thinking skills necessitates learners engaging in experimentation, independent research, and thoughtful reflection at each step of the process. It is the researcher's hope that virtual laboratories can be employed to address these challenges.

Hence, the current research highlights the significance of utilizing virtual laboratories for the development of metacognitive thinking skills in the field of physics.

Based on the above, the research problem is defined by the following main question: What is the impact of using virtual laboratories on the development of certain metacognitive thinking skills among female students in the third grade of secondary school in the subject of physics?

Literature Review

Virtual Laboratories

Virtual laboratories have gained popularity in education as an effective mechanism for teaching practical concepts compared to traditional laboratory environments, as they provide a realistic learning environment that simulates real-world scenarios (Shadbad et al., 2023).

Virtual laboratories are programmable laboratories that simulate real laboratories, allowing learners to conduct experiments remotely for any number of times. They compensate for the absence of physical lab equipment and enable the coverage of a wide range of course concepts through virtual experiments, which is difficult to achieve in reality due to time constraints and limited laboratory availability (Bajili, 2019, p. 125). In another definition, it is described as a virtual reality environment that simulates the real world for the purpose of discovery-based learning (Pramono et al., 2019, p. 2). According to Qaham (2021, p. 62), it is an electronic learning environment that allows students to apply practical laboratory experiments related to science subjects in a virtual manner that simulates real-world applications. These experiments are presented on a computer screen in the form of static and animated graphics accompanied by sound effects, providing the student or user with the sensation of being present at the experimental site. Virtual laboratories are also referred to by Aripin and Suryaningsih (2020, p. 1) as computer programs used to conduct experiments through web simulation or standalone applications.

Based on the previous definitions, we notice a consensus that virtual laboratories:

- Assist in conducting cost-effective laboratory experiments;

- Help students perform experiments in a safe manner without exposing them to any risks encountered in real laboratories;
- Represent a step towards the development of traditional laboratories to keep up with advancements;
- Foster thinking skills and decision-making abilities without any negative effects;
- Enable obtaining results similar to those obtained from traditional laboratories;
- Allow for the repetition of experiments and interactions without a maximum limit of repetitions and with minimal effort.

The field of education encompasses a wide range of available options and multiple virtual laboratories for science teachers, as indicated by Rodriguez and García (2017). They classified these options as follows:

1. Fully realistic laboratories that require continuous maintenance and are more prone to errors;
2. Representational laboratories with components that simulate reality, easy to develop, and less expensive to maintain, but offer a lower level of realism;
3. Hybrid laboratories, which combine the previous two types, aiming to leverage the advantages of each.

Recently, some improvements have been made to representational laboratories as part of the development and support of virtual simulation to make them more realistic and increase their usability. One notable enhancement is the addition of three-dimensional (3D) capabilities (Bogusevschi & Muntean, 2020).

Virtual laboratories, as highlighted by Belfaqih (2020), introduce novel attributes that surpass the limitations of traditional laboratories. Notably, these features encompass the opportunity to carry out hazardous experiments that would be infeasible in a conventional setting, emphasizing the actual execution of experiments, and promoting individualized learning through self-paced student engagement. Moreover, virtual laboratories contribute to the integration of technology in education, while simultaneously saving time by expediting the experimental process. Furthermore, their capacity to record experiments and preserve results allows for convenient accessibility at any given moment, providing an added advantage over conventional laboratory practices.

As highlighted by Almatiri (2017), virtual laboratories present an array of advantages. First, the ability to repeat experiments facilitates in-depth exploration and observation, enhancing learners' application of theories and physical laws. Second, the absence of limitations on the number of concurrent students, given sufficient bandwidth and accommodating software, fosters a seamless learning experience. Third, virtual laboratories promote teamwork, enabling learners to collaborate and strengthen their sense of cohesion. Moreover, these laboratories transcend temporal and spatial constraints, offering enhanced precision and control, which subsequently reduces error rates. Additionally, their diverse resources facilitate comprehension of various scientific phenomena without incurring the significant budgetary demands associated with traditional, specialized laboratories. Lastly, the user-friendly and reliable virtual laboratory software provides enjoyable and engaging experiences, further elevating the appeal and utility of virtual laboratories in educational contexts.

Metacognitive Thinking

Metacognitive thinking is, in our opinion, one of the highest forms of thinking, not being an ordinary pattern but rather a superior and elevated type of thinking. his is because thinking about thinking, in order to solve problems, address educational situations, and perform tasks, requires a sequential set of lines of thought centered on the cognitive activity of the learner, which can be developed through the cultivation of learners' experiences through training and practice.

We consider metacognitive thinking skills as important thinking skills, and they have recently received significant attention and extensive study due to their demonstrated effective impact on the development of thinking processes and the ability to produce a generation capable of problem-solving and decision-making.

There are multiple definitions for Metacognitive thinking skills, including the following:

The definition provided by Al-Mashkor (2022) states that Metacognitive thinking skills are a set of skills that manage higher-order thinking activities, focusing on self-regulation skills and including awareness of the necessary decisions to accomplish tasks, attention control, and positive orientations, as well as the skills required for performing practical tasks, which include declarative, procedural, and conditional knowledge, and the skills of procedural regulation, including planning, organizing, and continuous evaluation during task execution..

Additionally, Al-Awfi (2022, p. 140) defines Metacognitive thinking skills as a set of cognitive activities practiced by the student during cognitive processes, with an understanding of the intended goal. This includes engaging in planning, monitoring, and continuous evaluation during task execution and activities.
Sternberg categorized the cognitive skills of metacognition into three main skills: planning, monitoring, and evaluation. Each skill encompasses several sub-skills. This research primarily focuses on the skills of planning, monitoring, and control. The following provides a detailed description of these two skills (Al-Shatti & Al-Youcef, 2018):

- **Planning**: refers to the ability to identify the desired goal and select an appropriate strategy. It involves predicting potential difficulties and obstacles and knowing how to cope with them. It encompasses the following sub-skills: recognizing the presence of a problem and determining its nature, identifying the appropriate strategy and execution method, organizing the sequence of steps or processes, anticipating potential difficulties or errors, confronting challenges and mistakes, and the ability to predict desired or expected outcomes;
- **Monitoring and Control:** it involves monitoring and regulating one's thinking during the learning process, so that the learner is aware of their thinking and can guide it according to the plans they have established. It encompasses the following sub-skills: setting the intended goal at the center of attention, identifying sub-goals, maintaining the sequence of steps in order, recognizing the appropriate time to transition to the next step, selecting the step that aligns with achieving the desired goal, identifying difficulties and errors, and understanding how to overcome challenges and overcome mistakes.

Developing metacognitive thinking skills is the gateway that allows learners to keep up with the advancements and progress in scientific knowledge, particularly in the field of science, whether theoretical or experimental. By directing students' attention towards identifying problems and challenges, it is possible to enhance their thinking skills in science teaching. By guiding them to reflect on their own thinking, or what is known as metacognitive thinking skills, they are enabled to monitor and direct their thinking towards finding the best solution and excluding inappropriate ones. Acquiring thinking skills, especially thinking about thinking, is essential for science teaching, as it requires planning for scientific and practical problem-solving and self-monitoring during task execution through self-questioning and possessing appropriate assessment of problem-solving (Al-Jaid & Al-Jahni, 2018).
Since the subject of science provides a fertile environment abundant with educational situations, scientific problems, and cognitive and practical skills, the development of skills in general, and metacognitive thinking skills in particular, is essential to meet the needs and desires of learners and guide them towards using their minds and thinking within scientific methods and approaches to utilize knowledge and skills in scientific and real-life situations.
Based on the review if the liretarure, and the general goal of this research, the main question of this study branches into the following three sub-questions:

1. What are the metacognitive thinking skills that female students in the third grade of secondary school should acquire through the use of virtual laboratories?
2. What is the impact of using virtual laboratories on the development of metacognitive thinking skills among female students in the third grade of secondary school in the subject of physics?
3. What is the proposed instructional design for enhancing metacognitive thinking skills through the application of virtual laboratories?

Theoritical Framework

The Cognitive Theory

This theory refers to how knowledge is received from sensory inputs (sight, hearing, imagination, memory, recall, thinking, and other processes) that illustrate the stages involved in mental processes (Al-Shibl & Alsaqri, 2022).
The cognitive theory has elucidated that knowledge acquisition occurs through organizing cognitive aspects and through internal thinking processes that occur during the learning process. Situations related to goals are identified and changes in the structure are determined. Learning through this theory enables students to easily comprehend the material based on the results they have reached. The relationship between prior and new knowledge facilitates the restructuring of cognitive frameworks in individuals, allowing for a deeper understanding of the presented material (Saleh, 2022).

The Constructivist Theory

Jean Piaget, Lev Vygotsky, and Jerome Bruner were the pioneers of the Constructivist Theory in the early 20th century. One of the fundamental ideas embraced by this theory is that knowledge and understanding are not acquired passively, but rather actively through personal experience and hands-on activities. It further assumes that individuals can construct knowledge through their interactions with the environment. Constructivism focuses on how individuals learn, rather than how teachers instruct. It recognizes knowledge as subjective and relative (Fatimah et al., 2022).

Sasan and Rabillas (2022) add that The Constructivist Theory is a philosophy of teaching and learning that posits that perception (learning) is a result of blending new information with what learners already know. Constructivism focuses on the necessary scenarios and content for multimedia learning, such as research applications and decision-making, in addition to fostering collaboration and active participation among learners. Constructivists believe that the environment in which a subject is taught, as well as students' beliefs and attitudes, have an impact on learning.

The constructivist theory can be applied in the design of simulation programs to provide features of real practice for learning tasks within virtual laboratories. Through such programs, learners can be placed in an active learning position where they interact with the components of the virtual lab environment, including experiments and content, prompting them to acquire new knowledge and experiences that contribute to their existing cognitive structure. This utilization of the constructivist theory in simulation program design was highlighted by Al-Jazar (2018).

Theory of Process-Based Learning

This theory refers to training the learner to engage in metacognition, envisioning how they understand facts and comprehend the information they study. It also involves training them on how to use this information in developing their own system, which they employ in performing educational and general life tasks. According to the theory of process-based learning, the four main processes that should be present in every plan or project are research, performance, monitoring, and verification. These processes significantly align with metacognitive skills, particularly the monitoring process, which can be considered a blend of organizational and planning skills. The verification process, on the other hand, relates to the skill of assessment and evaluation, which is also a metacognitive skill (Al-Ghareeri, 2017).

Information Processing Theory

The Information Processing model is one of the modern cognitive theories, and cognitive psychology cannot be discussed without addressing this model. The invention and evolution of the computer, specifically the digital computer, have greatly contributed to the development of this theory. This theory assumes a resemblance between human cognitive activity and the programming and functioning methods of computers (Al-Ghareeri, 2017).

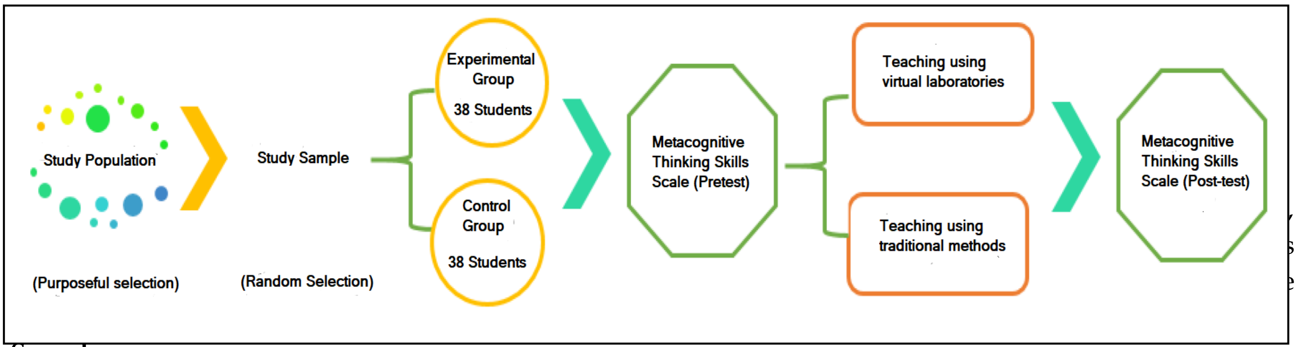
The Information Processing theory relies on the notion that the five human senses serve as information carriers through neural channels to the cognitive structure. Within this structure, various mental processes take place, including short-term and long-term memory, as well as cognitive processes such as recall, retrieval, and imagination. This parallel can be observed in computer systems, highlighting the importance of bridging modern technologies, such as computers, with learners' cognitive activity. This connection is facilitated through the utilization of planning and organizational skills, as well as the application of monitoring and control skills to regulate performance and achieve accurate results in problem-solving. All of these abilities are considered cognitive skills (Al-Ghareeri, 2017).

METHODS

1- Research Methodology

The researcher adopted a quasi-experimental design to determine the effectiveness of the independent variable (use of virtual laboratories) on the dependent variable, which is the development of Metacognition skills.

Figure 1. The experimental design of the study (researchers' design).



Sample

The research sample was selected ramdomly, consisting of 30 female students equally divided between the control group (15 students) taught using traditional methods, and the experimental group (15 students) taught using virtual laboratories.

Assessment tools

The Cognitive Thinking Skills Scale developed by the researcher (2022)

Aim

The researcher prepared this scale aiming to assess the metacognitive thinking skills among third-grade female students in high school. It is measured in this study by the total responses of the students to the scale items, and it is represented by the overall score obtained by the students on this scale. The researcher developed the scale with the assistance of metacognitive thinking scales, such as the Schraw and Dennison scale (1994), which was translated to Arabic by Al-Jarrah and Abidat (2011), and Shammout scale (2015), to explore the process of constructing a scale for these skills that is aligned with the subject of physics.

Steps to Developing the Scale

Step One: Defining the scale's dimensions

The researcher conducted a survey of available literature on the development of scales and subsequently constructed the scale in two dimensions as follows:

1. The first dimension, "Planning Skill," included 10 items or statements that measure the student's ability to identify the goal to be achieved, select appropriate strategies, anticipate potential difficulties and obstacles, and determine coping methods;
2. The second dimension, "Monitoring and Control Skill," included 10 items or statements that measure the student's ability to monitor and regulate their thinking during the learning process, ensuring awareness of their thinking and the ability to direct it according to the devised plans.

Step Two: Formulating Scale Items

The researcher ensured precision, clarity, and single-meaning formulation while crafting the scale items. We aimed to make the items understandable and expressed in Arabic language, taking into consideration the formulation of some statements in a positive direction and others in a negative direction. Based on these considerations, the paragraphs were formulated for each dimension, and thus the scale took its initial form.

Step Three: Presentation to the Reviewers

The researcher presented the scale items to a group of reviewers to study the tool and seek their opinions regarding:

- The suitability of the scale items in detecting the level of metacognitive thinking skills among third-grade female students;
- The clarity of the scale items and their linguistic and scientific soundness;
- The clarity of the scale instructions.

After incorporating the reviewers' feedback and making revisions, the scale was finalized and consisted of 20 items, equally distributed between the two skills: planning and monitoring/control.

The fourth step: Scoring the Scale

The response to the metacognitive thinking skills items is assessed using a Likert scale (Always - Often - Sometimes - Rarely - Never). The items are scored in order (5 - 4 - 3 - 2 - 1), and based on this, the scale scores range from 20 to 100 points.

The fifth step: Validity and Reliability of the Metacognitive Thinking Skills Scale

The researcher administered the scale to the participants of the pilot sample, consisting of 30 female students from outside the research sample who were in the third year of secondary school, in order to ensure its validity and reliability as follows:

First: Validity

a) Face validity (Expert Validity):

The researcher presented the scale to experts who are faculty members in Saudi universities specializing in educational technology, curriculum, and teaching methods. This step aimed to ensure the clarity of instructions and item formulation, as well as to gather expert opinions on the adequacy of the scale in terms of the number of items, comprehensiveness, content diversity, and assessment of linguistic formulation and presentation. The experts were invited to provide any relevant feedback, suggestions, or recommendations regarding modifications, changes, or deletions deemed necessary. The researcher carefully examined the experts' comments and suggestions, incorporating their feedback based on the recommendations and opinions of the peer review committee. The revised items were those on which the majority of experts agreed, with an agreement rate exceeding 80%.

b) Internal consistency reliability

The researcher calculated the internal consistency reliability of the Cognitive Thinking Skills Scale by computing the values of Pearson correlation coefficients between each item of the scale and the total score of the scale. Table 1 presents the results.

Table 1. Pearson Correlation Coefficients between Each Item of the Cognitive Thinking Skills Scale and the Total Score

Item Number	Correlation Coefficient	Item Number	Correlation Coefficient	Item Number	Correlation Coefficient	Item Number	Correlation Coefficient	Item Number	Correlation coefficient
1	0,602(**)	5	0,556(**)	9	0,492(**)	13	0,304(**)	17	0,453(**)
2	0,290(*)	6	0,492(**)	10	0,499(**)	14	0,480(**)	18	0,498(**)
3	0.501(**)	7	0,448(**)	11	0,433(**)	15	0,415(**)	19	.554(**)
4	0,412(**)	8	0,424(**)	12	0,506(**)	16	0,387(**)	20	0,443(**)

** Correlation coefficient significant at the 0.01 level *Correlation coefficient significant at the 0.05 level

Based on the findings presented in Table 1, it is evident that the correlation coefficients between the items comprising the Cognitive Thinking Skills Scale and the overall scale score yielded statistically significant results at the 0.01 or 0.05 significance level. These results strongly support the internal consistency of the scale, indicating that the items within the scale consistently measure the intended construct. Moreover, to further establish the construct validity of the Cognitive Thinking Skills Scale, the researcher examined the correlation between each individual item and the total score of its corresponding dimension. The results of this analysis are presented in table 2.

Table 2. Pearson correlation coefficients indicating the association between the score of each item and the total score of its corresponding dimension or skill

	Planning Skill				Monitoring and Control Skill		
Sequence	Correlation Coefficient	Sequence	Correlation Coefficient	Sequence	Correlation Coefficient	Sequence	Correlation Coefficient
1	0,801(**)	6	0,655(**)	1	0,642(**)	6	0,803(**)
2	0,360(**)	7	0,438(**)	2	0,630(**)	7	0,596(**)
3	0.564(**)	8	0,543(**)	3	0,559(**)	8	0,422(**)
4	0,687(**)	9	0,657(**)	4	0,318(**)	9	0,653(**)
5	0,731(**)	10	0,653(**)	5	0,616(**)	10	0,303(**)

** Correlation coefficient significant at the 0.01 level

From Table 2, it is evident that the Pearson correlation coefficients for the scores of each item with the total score of the corresponding skill were all statistically significant at a significance level of 0.01. These coefficients were generally high, indicating a satisfactory level of internal consistency for the scale.

Second: reliability

The reliability of the Cognitive Thinking Skills scale was calculated using Cronbach's alpha and split-half reliability methods as follows.

Table 3. reliability coefficients using both Cronbach's alpha and split-half reliability methods for the Cognitive Thinking Skills scale.

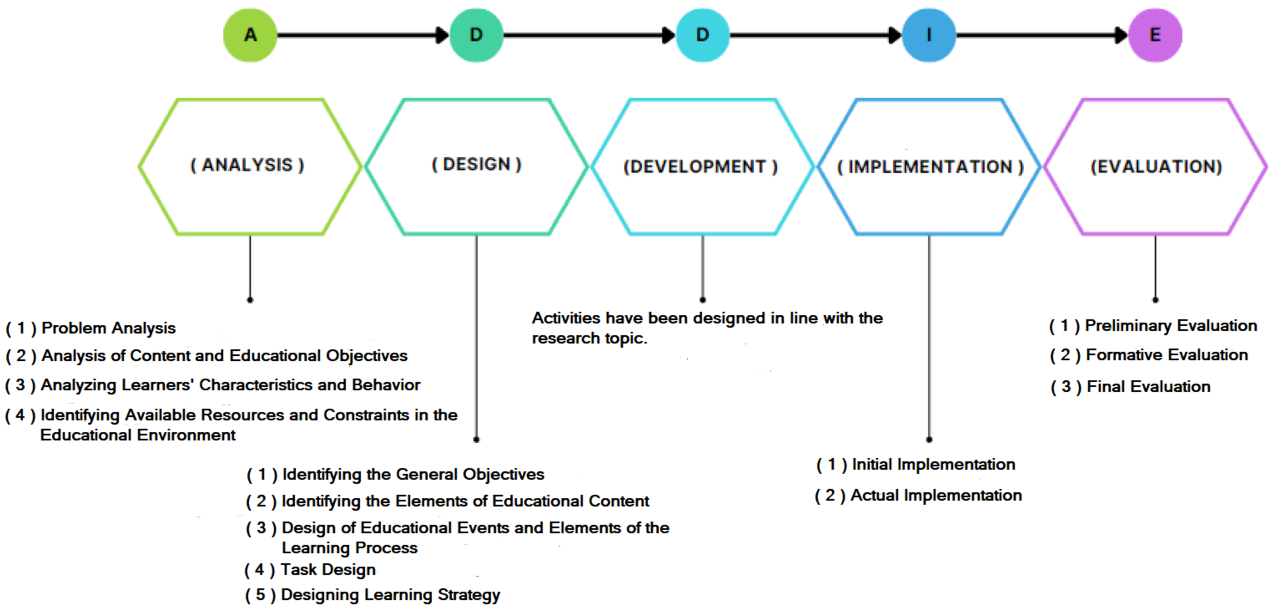
Dimensions	Number of Items	Cronbach's Alpha Coefficient	Split-half Method	
			Spearman-Brown	Jettman equation
Planning Skill	10	0,87	0,77	0,77
Monitoring and Control Skill	10	0,73	0,71	0,72
Total Score	20	0,83	0,77	0,78

From Table 3, it can be observed that the reliability coefficients, according to Cronbach's alpha, for the dimensions of the Cognitive Thinking Skills scale ranged from 0.78 to 0.73 for the respective skills. The overall reliability coefficient for the entire scale was found to be 0.83. Similarly, the split-half reliability coefficients, using the Spearman-Brown equation, for the dimensions of the Cognitive Thinking Skills scale ranged from 0.77 to 0.71, with an overall reliability coefficient of 0.77 for the respective skills. Furthermore, the coefficients of stability, according to Guttman's equation, for the dimensions of the Cognitive Thinking Skills scale were found to be 0.77 to 0.72 for the respective skills, with an overall reliability coefficient of 0.78. These reliability coefficients indicate good levels of stability for the scale, suggesting that the scale demonstrates good reliability.

4. 3- The Proposed Instructional Design

The researcher adopted the ADDIE model, which is considered one of the best instructional design models. It is a systematic approach to the instructional design process that provides designers with a procedural framework to ensure that educational products are effective and efficient in achieving their objectives. The general framework of the ADDIE Model consists of five major stages, from which the model derives its name. Figure 1 presents a detailed description of these stages.

Figure 2. The ADDIE instructional design model



The Analysis Phase

The analysis phase typically includes the following processes:

a) Problem Analysis

Education is no longer limited to providing learners with information and presenting it to them in a ready-made format, where the role of the teacher is to demonstrate that information and store it in the learners' memory until the time of examination. Education has shifted towards focusing on using scientific thinking skills in a scientific manner, employing innovative teaching techniques, particularly virtual laboratories, through which the mind is engaged in addressing the challenges that students encounter in the simulated learning environment designed for them in the virtual lab.

b) Analysis of Content and Educational Objectives

Each chapter in the physics curriculum encompasses educational objectives that have been formulated by the Ministry of Education, and these objectives are attained by the end of each chapter. These objectives outline the final tasks that learners will be capable of performing upon completion of the instructional process. Furthermore, each experiment was linked to its intended objective, as indicated in Table 4.

Table 4. The link between each experiment and its objective

Chapter	Objective	Experiment
First	The student should describe how diffraction proves that light is composed of waves. The student infers the effect of overlapping light colors and mixed dyes. The student links the Doppler effect to the frequency and wavelength of light.	The diffraction of light waves. The experiment of color mixing. The experiment of the Doppler effect.
Second	The student demonstrates the law of reflection practically. The student discovers the positions of the images formed by spherical mirrors.	The reflection experiment. The mirror reflection experiment.
Third	The student deduces the effect of light refraction on both the speed and the frequency and wavelength of light. The student discovers the relationship between the angle of incidence and total internal reflection. The student describes the positions of the images formed by lenses.	The wave model of refraction. The experiment of total internal reflection. The experiment of refraction in lenses.

c) Analyzing Learners' Characteristics and Behavior

The aim of this stage was to identify the students' abilities, knowledge, behavior, and motivations, as well as their prior achievements regarding their skills in using computers. Learners cannot improve their skills unless they actively participate in the learning process. If the educational process requires them to use virtual laboratory software, and they are not proficient in using computer programs in general, their opportunities to achieve the objectives will undoubtedly be weak. Therefore, prior knowledge and acquired skills should be included as part of the analytical process.

- Mental Development

1. General intelligence grows rapidly, and cognitive abilities begin to differentiate, reaching the student's maximum potential by the end of this stage;
2. Learning speed and preferences for certain subjects over others become evident;
3. The capacity to learn skills and acquire knowledge develops;
4. Perception evolves from sensory to abstract levels;
5. Attention span increases and sustains for longer durations;
6. Reliance on comprehension and reasoning replaces trial and error or rote memorization;
7. Thinking skills improve, including problem-solving, deductive and inductive reasoning, judgment, analysis, and synthesis. The ability to plan and design emerges;
8. Generalization and abstraction abilities enhance;
9. Greater capacity for innovation becomes apparent;
10. Strategies and habits of memorization, self-study, and self-expression become evident.

- Previous Knowledge

The first three chapters of the Physics 3 course were selected, which include the basics of light, reflection in mirrors, and refraction in lenses. Based on the scope and sequence matrix of the Physics 3 curriculum, we find that a brief introduction to key terms in light, such as reflection, refraction, and diffraction, has been covered. Therefore, the students have a background, albeit limited, compared to what will be studied in this stage.

- Technical Skills

The third-grade secondary school students possess excellent skills in using computers, navigating websites, and utilizing internet connectivity.

d) Identifying Available Resources and Constraints in the Educational Environment

During the analysis phase, it is essential to identify the available resources in the educational environment and determine the conditions and capabilities that need to be met for the success of the educational process. These include the following:

- Environmental facilities: a dedicated learning resource room has been allocated for meetings and conducting the experiment.
- Material resources:
  - Provision of a fast internet network;
  - Smart devices;
  - Display screen.

The Design Phase

a) Identifying the General Objectives

The overall objective of using virtual laboratories is to teach the first three chapters of the Physics 3 course (Fundamentals of Light, Reflection in Mirrors, and Refraction in Lenses) with a focus on developing Metacognition skills among third-grade secondary school female students, in light of current research.

b) Identifying the Elements of Educational Content

The educational content for the virtual laboratory was determined based on the prescribed curriculum for Physics 3 in the third grade of secondary school. The researcher chose the first three chapters due to their relevance to the current research objectives. The researcher divided the lessons of the first three chapters in the Physics 3 curriculum (Fundamentals of Light - Reflection in Mirrors - Refraction in Lenses) into sessions according to a proposed plan by the researcher, as shown in Table 5.

Table 5. The Division of Sessions for the First Three Chapters in the Physics Curriculum

Day	Date	The Subject of the Lesson	The Title of the Experiment
Tuesday	August 30, 2022	The Wavy Nature of Light	Refraction of light waves
Sunday	September 1st, 2022	Mixing Light Rays	Experiment of color mixing.
Tuesday	September 6th, 2022	Doppler Effect	Doppler effect experiment.
Sunday	September 11th, 2022	Reflection from Mirrors	Reflection experiment.
Tuesday	September 13th, 2022	Spherical Mirrors	Mirror reflection experiment
Sunday	September 18th, 2022	The Wavy Model of Refraction	The wavy model of refraction.
Tuesday	September 20th, 2022	Total Internal Reflection	The experiment of total internal reflection.
Sunday	September 26th, 2022	Images in Convex and Concave Lenses	The experiment of refraction in lenses.

c) Task Design

Eight different tasks were designed according to the educational objectives to be achieved, distributed across the selected three chapters, where each task assesses two skills: planning and monitoring/control.

d) Designing Learning Strategy

The researcher relied on several strategies to serve the intended educational content, including:

- Effective discussion: It is a verbal strategy that relies on dialogue to stimulate prior knowledge and concepts and elevate the level of cognitive activity to construct new knowledge;
- Programmed learning: Activities were divided into small tasks, where progression between tasks was only allowed upon completion of the preceding task;
- Performance-based assessment: Cognitive assessment of the third-grade secondary school students was conducted through computer-based interaction via the internet, with the presence of the researcher. The researcher met with the students to emphasize the importance of studying using virtual laboratories, explain the content's significance, educational objectives, and guide them on navigating within the virtual lab according to their individual needs and capabilities within the research sample.

The Development Phase

The aim of this stage was to bring about transformation and innovation in the educational process. The researcher did not rely on the practical skills guide provided by the Ministry of Education, but rather designed activities that aligned with the research topic and did not contradict the guidelines.

The Implementation Phase

At this stage, the practical application of the experiment was carried out according to the following steps:

a) Initial implementation

1. The scale was implemented on the survey sample individuals from the research community and outside the research sample, consisting of 20 female students from the third year of high school - the science section, in order to ensure the validity and reliability of the scale. Notes were

collected regarding the clarity and understanding of the statements for the purpose of improving them in their final form;

2. A meeting was held with the selected students and they were prepared to participate in the experiment. The objective of the experiment was explained to them, and the implementation plan was clarified. They were also introduced to the cognitive thinking skills and their previous experiences in dealing with virtual laboratories were assessed.

b) Actual implementation

The actual implementation of using virtual laboratories in teaching began on Tuesday, August 30, 2022 and continued for a duration of one month. This was done in coordination with the resource coordinator, utilizing the resource room for two days per week.

The Evaluation Phase

The aim of this stage was to refine all stages of the experiment, starting with the pre-experiment phase (preliminary evaluation). The scale was presented to the assessors to ensure its validity and suitability for use by the participants in the experiment, and necessary modifications were made. During the experiment (formative evaluation), the performance of the participants was monitored, and guidance and instructions were provided to ensure the achievement of the educational objectives of the laboratories. This was done through the use of an attached performance monitoring card. Finally, the post-experiment phase (final evaluation) involved the application of post-experiment tools and statistical analysis of the data.

Verifying the compatibility of the two groups

The research tool "Cognitive Metacognitive Thinking Skills Scale" was applied as a pretest to both the control group and the experimental group to ensure their equivalence. The results are presented in table 6.

Table 6. "T" test on the two independent samples to verify the equivalence between the experimental and control groups in the pretest application of Metacognition Skills Scale.

Tool	Group	Sample size	Average	Standard Deviation	Degree of Freedom	T Value	Significance Level	Significance
Planning Skill	Control Pretest	15	38,9	4,9	28	0,474	0,639	Insignificant
	Experimental Pretest	15	39,7	4,4				
Monitoring and Control Skill	Control Pretest	15	38,6	5,2	28	0,452	0,655	Insignificant
	Experimental Pretest	15	39,3	3,5				

The results of the independent samples t-test in the previous table indicate a lack of statistically significant differences between the mean scores of the experimental group and the control group in the pre-application of the Cognitive Thinking Skills Scale for the three topics of the first three chapters in the Physics 3 course (Light Basics - Reflection in Mirrors - Refraction in Lenses). The values of the t-statistics for Metacognition skills (Planning - Monitoring and Control) were non-significant at the 0.05 level. Therefore, the research groups were considered equivalent prior to the application in terms of their levels of cognitive thinking skills (Planning - Monitoring and Control).

Statistical Methods

To achieve the research objectives and analyze the obtained data, the statistical analysis of the data was conducted using the SPSS software: Statistical Package for the Social Sciences v.22. The following statistical methods were employed:

- Cronbach's alpha and split-half reliability were used to verify the reliability of the research instrument;
- Pearson correlation coefficient was employed to assess the internal consistency validity of the research instrument;
- Means and standard deviations, as well as the independent samples t-test, were conducted to examine the significance of differences between the experimental and control groups, comparing the mean differences in the scores of the participants in the experimental group between the pre-test and post-test administrations of the measure, and determining the statistical significance of these differences;
- Calculation of the eta-squared (η2) value was performed to determine the effect size of the independent variable on the dependent variable.

Results, Analysis, and Discussion

Results and Discussion Related to Hypothesis 1

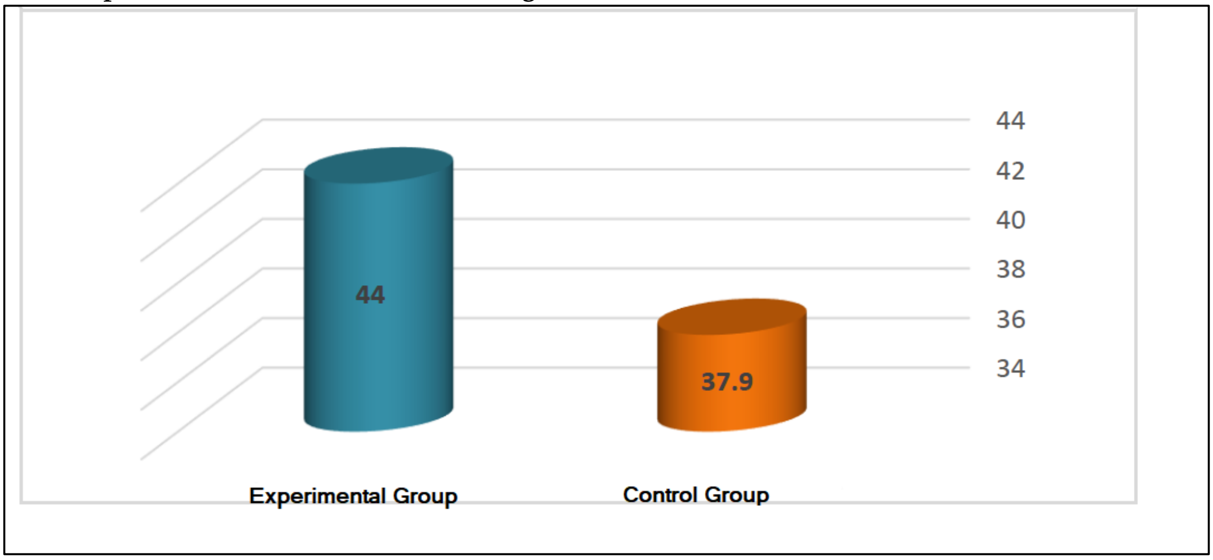
The first hypothesis assumes that "there are no statistically significant differences at a significance level of 0.05 between the mean scores of the control and experimental groups in the planning skill in the post-test administration of the Cognitive Thinking Skills measure." To verify the validity of this hypothesis, the researcher conducted an independent samples t-test for the scores of the students in the control and experimental groups on the planning skill in the post-test administration of the Cognitive Thinking Skills measure. The results are presented in table 7.

Table 7. "T" test to assess the significance of the differences between the mean scores of the control and experimental groups in the planning skill in the post-test administration of Metacognition Skills Scale.

Tool	Groups	Sample size	Average	Standard Deviation	Degree of Freedom	T Value	Significance Level	Significance
Planning Skill	Control Post-test	15	37,9	6,6	28	3,093	0,004	Insignificant
	Experimental Post-test	15	44,0	3,9				

The results of the "T" test for the independent samples in the previous table indicate statistically significant differences between the mean scores of the experimental group and the control group in the planning skill of Metacognition Skills measure in the post-test administration. The calculated value of "T" was 3.093 with a significance level of 0.004, which is lower than 0.05, indicating the presence of a statistically significant difference between the two groups in the planning skill. These differences favored the experimental group, which was taught using the virtual laboratory. The average scores of students in the experimental group in the planning skill were 44.0 compared to 37.9 for students in the control group. Therefore, this result indicates the rejection of the null hypothesis, as the results indicate statistically significant differences between the mean scores of the experimental group and the control group in the planning skill of the Cognitive Thinking Skills measure in the post-test administration, in favor of the experimental group.

Figure 3. The differences in the mean scores between the control and experimental groups in the planning skill in the post-test administration of Metacognition Skills Scale.



The above result is consistent with the findings of Al-Ghacham and Al-Hammadi’s (2017) study, which demonstrated the effectiveness of employing the virtual laboratory-based learning model in developing creative thinking and planning abilities among secondary school students. Additionally, Qaham's (2021) study confirmed the effectiveness of using virtual experiments in teaching scientific inquiry skills in science subjects. The researcher indicates that the use of virtual laboratories has helped students to have a sense of freedom, allowing them to utilize their cognitive abilities effectively in designing, organizing, and managing laboratory experiments, as well as evaluating their performance and ensuring the achievement of their goals. Since the use of the virtual laboratory strategy deviates from routine and stereotypical approaches, it has captured the students' attention in the lesson. Moreover, focusing on the development Metacognition skills and arousing the students' interest in them has led to their awareness of these skills, their commitment to applying them, and their self-reliance in overcoming the difficulties encountered in implementing these skills in general.

Results and Discussion Related to Hypothesis 2

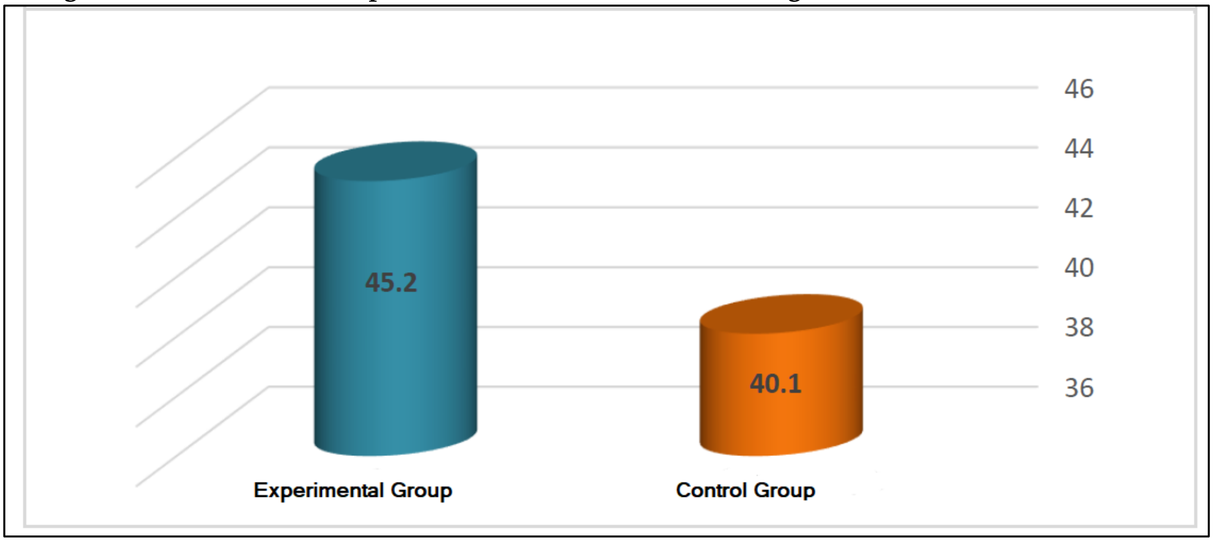
The second hypothesis assumes that "there are no statistically significant differences at the 0.05 significance level between the mean scores of the control group and the experimental group in the skill of monitoring and control in the post-application phase of the cognitive thinking skills measure." To verify the validity of this hypothesis, the researcher conducted an independent samples t-test for the scores of the students in the control and experimental groups in the skill of monitoring and control in the post-application phase of the cognitive thinking skills measure.

Table 8. "T" test to assess the significance of the differences between the mean scores of the control and experimental groups in the monitoring and control skill in the post-test administration of Metacognition Skills Scale.

Tool	Groups	Sample size	Average	Standard Deviation	Degree of Freedom	T Value	Significance Level	Significance
Control and Monitoring Skill	Control Post-test	15	40,1	5,4	28	2,919	0,007	Insignificant
	Experimental Post-test	15	45,2	4,2				

The results of the independent samples t-test presented in the previous table indicate the presence of statistically significant differences between the mean scores of the experimental group and the control group in the skill of monitoring and control of the cognitive thinking skills measure in the post-application phase. The calculated value of the t-statistic was 2.919, and the significance level was 0.007, which is less than 0.05, indicating the existence of a statistically significant difference between the two groups in the skill of monitoring and control. These differences favored the experimental group, which was instructed using the virtual laboratory model, with an average score of 45.2 compared to 40.1 for the control group. Therefore, this result suggests that the second hypothesis, which stated the absence of statistically significant differences between the mean scores of the experimental and control groups in the skill of monitoring and control, was not supported. The results indicate the presence of statistically significant differences between the mean scores of the experimental group and the control group in the skill of monitoring and control of the cognitive thinking skills measure in the post-application phase, in favor of the experimental group.

Figure 4. The differences in the mean scores between the control and experimental groups in the monitoring and control skill in the post-test administration of Metacognition Skills Scale.



This result is consistent with the study conducted by Hung and Tsai (2020), which revealed that the virtual laboratory had a positive impact on metacognitive thinking skills and students' competencies in data modeling. Similarly, the study by Manikowati (2019) demonstrated that the use of virtual laboratories can have more positive effects on students' knowledge construction and organization beyond mere knowledge acquisition in practical learning. Furthermore, the study by Yusuf and Widyaningsih (2020) showed that the majority of students exhibited favorable responses to their learning experiences with cognitive thinking skills. Moreover, this result is consistent with the theoretical principles regarding the role of virtual laboratories in developing monitoring and control skills. As mentioned by Almatiri (2017), virtual laboratories offer advantages such as focusing on actual experiment execution and providing a high level of accuracy and

precision, thereby reducing human errors. Additionally, the repetition of experiments allows learners to analyze and observe experimental trends, enabling them to apply theories or physical laws more effectively.
The researcher believes that the use of virtual laboratories with the experimental group has contributed to catering to the diverse abilities of students in teaching and learning, taking into account individual differences among them. This aligns with psychological theories in education and learning, as it was achieved through repeated experimentation and the use of multimedia to illustrate learning topics, including auditory and visual elements, as well as a combination of both. This approach effectively captures the attention of students towards monitoring laboratory experiments and how to precisely control them(Alanzi & Alhalafawy, 2022a, 2022b; Alhalafawy, Najmi, Zaki, & Alharthi, 2021; Alhalafawy & Tawfiq, 2014; Alhalafawy & Zaki, 2019, 2022; Alshammary & Alhalafawy, 2022, 2023; Alzahrani & Alhalafawy, 2023; Alzahrani & Alhalafawy, 2022; Alzahrani, Alshammary, & Alhalafawy, 2022; Najmi, Alhalafawy, & Zaki, 2023; Zeidan, Alhalafawy, & Tawfiq, 2017; Zeidan, Alhalafawy, Tawfiq, & Abdelhameed, 2015).
The effect size was calculated using the eta-squared (η^2) formula, The results are as presented in table 9.

Table 9. Calculating the effect size using the eta-squared equation is aimed at determining the impact of using virtual laboratories on the development of Metacognition skills (planning, monitoring, and control).

Skill	Pre-test Average	Post-test Average	T Value	Significance Level	Eta-squared Value
Planning	39,7	44,0	2,819	0,009	0,22
Monitoring and Control	39,9	45,2	4,150	0,000	0,38

From Table 9, we find that the effect size of using virtual experimentation in teaching the first three units of the Physics 3 course (Fundamentals of Light - Reflection in Mirrors - Refraction in Lenses) on the development of planning skills among female students in the third year of secondary school in Jeddah city was determined using the eta squared equation. It was found to be 0.22 for planning skills and 0.38 for monitoring and control skills. These results indicate that the improvement observed in the levels of Metacognition skills (planning, monitoring, and control) among female students in the experimental group in the post-application phase can be attributed to the use of virtual experimentation in teaching the first three units of the Physics 3 course (Fundamentals of Light - Reflection in Mirrors - Refraction in Lenses). This effect is substantial, as indicated by the large effect size.
As evident in Table 9, the effect size of the independent variable, the use of virtual experiments in teaching the first three units of the Physics 3 course (Fundamentals of Light - Reflection in Mirrors - Refraction in Lenses), on the dependent variable, the levels of Metacognition (planning, monitoring, and control) among female students in the third year of secondary school in Jeddah, was large. This result can be interpreted by the fact that employing virtual experiments in physics and science education, in general, provides learners with significant capacity to envision concepts that are difficult to imagine realistically. This technique enables learners to observe, interact with, and monitor experimental procedures, facilitating their control over the experiments. By allowing step-by-step and repeated practice through software and assistive technologies provided by virtual laboratories, learners can engage in multiple iterations of the experiments. The researcher also believes that the instructional design adopted in implementing the virtual experiment strategy played a significant role in developing Metacognition skills (planning, monitoring, and control) among female students in the third year of secondary school in Jeddah, as evidenced by the activities and worksheets executed by the students.

Conclusion

The emphasis on conducting training courses for physics teachers is crucial as it enhances their teaching practices and modern techniques, including virtual experiments, which, in turn, aid in the development of Metacognition skills. This technology's application in teaching other sciences that rely on laboratory experiments is recommended due to its positive impact on Metacognition skill development. Moreover, leveraging virtual experiments helps address obstacles students face in activating the practical aspect of studying physics and science. Therefore, teacher education colleges should establish specialized laboratories to promote the use of computer technologies and virtual experiments in teaching science subjects. Additionally, creating an Arabic website for virtual experiments on the Internet is essential to facilitate teachers' and students' access to this technology.
To further integrate Metacognition skills in physics curricula at the secondary level, incorporating relevant activities and exercises is advisable. Encouraging the use of the Metacognition skills scale developed by the

researcher in this study among teachers and supervisors is recommended, with potential enhancements to measure Metacognition skills in all science subjects.

Future research directions include conducting a study to explore the current teaching practices of female physics teachers, focusing on the development of students' Metacognition skills across different educational stages. Investigating the relationship between students' Metacognition thinking skills and their academic achievement levels in the secondary stage is also a valuable avenue for research. Moreover, evaluating the effectiveness of a training program based on metacognition on students' academic achievement and attitudes towards physics would provide valuable insights for educational practice.

Declarations

Conflict of Interest

No potential conflicts of interest were disclosed by the authors with respect to the research, authorship, or publication of this article.

Ethics Approval

The formal ethics approval was granted by the General Directorate of Education in Jeddah Province under the number 4400073715 on August 22nd, 2022. Moreover, we adhered strictly to well-established research ethics principles. The experimental procedures were also approved by the institution where the study was conducted, ensuring the utmost ethical conduct.

Funding

No specific grant was given to this research by funding organizations in the public, commercial, or not-for-profit sectors.

Research and Publication Ethics Statement

We, as the authors, consciously assure that for the manuscript, the following is fulfilled:

- This material is the authors' own original work, which has not been previously published elsewhere.
- The paper reflects the authors' own research and analysis in a truthful and complete manner.
- The results are appropriately placed in the context of prior and existing research.
- All sources used are properly disclosed.

Contribution Rates of Authors to the Article

The authors acknowledge that the first researcher made the primary contribution to this work, investing substantial effort and leading the research process, while the second researcher also made significant contributions that complemented the study's overall outcomes.

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