Guruku: Jurnal Pendidikan Profesi Guru Vol. 4 No. 2, Juni 2025
e-ISSN: 2964-5689 | Page: 98-115

(Original Research)

THE IMPACT OF VIRTUAL LABORATORIES ON DEVELOPING INTEGRATIVE CONCEPTS BETWEEN MATHEMATICS AND SCIENCE AMONG EIGHTH GRADE STUDENTS

Azhar Ali Hussein Ibrahim
Department of Education and Psychology, College of Education, University of Zakho, Kurdistan Region, Iraq
azhar.hussein@uoz.edu.krd

Zuher Ahmed Ali
Department of Medical Laboratory Technician, Technical Institute of Zakho, Duhok Polytechnic University, Kurdistan Region, Iraq
zuhir93@gmail.com

ABSTRACT

This study aimed to investigate the impact of virtual laboratories on developing integrative concepts between mathematics and science among eighth-grade students. The research adopted an experimental design with three equivalent groups: the first experimental group studied mathematics using virtual laboratories, the second experimental group studied science using virtual laboratories, and the control group studied using the traditional method. The sample consisted of 83 eighth-grade students from basic education schools in Duhok Governorate for the academic year 2024-2025. The researchers prepared an integrative concepts test consisting of 18 items distributed equally across three concept elements (definition, discrimination, application). The results revealed statistically significant differences between the three groups in the post-test of integrative concepts in favor of both experimental groups, with no significant difference between the two experimental groups themselves. Additionally, both experimental groups showed significant improvement in their integrative concepts understanding from pre-test to post-test. The effect sizes were large, confirming the educational importance of these differences. Based on these findings, the researchers recommended providing the necessary infrastructure for implementing virtual laboratories in schools, training teachers to use them effectively, and developing curriculum materials that highlight the connections between mathematics and science concepts. The study suggested conducting further research on the impact of virtual laboratories on other educational aspects and in different educational stages.

Keywords: *Virtual Laboratories, Integrative Concepts, STEM Education, Mathematics-Science Integration, Middle School.*

INTRODUCTION

The contemporary educational landscape is increasingly characterized by the integration of digital technologies, a transformation that has fundamentally altered how students engage with scientific and mathematical concepts. Virtual laboratories, in particular, have emerged as powerful educational tools that bridge the gap between theoretical knowledge and practical application, offering students immersive, interactive learning experiences that traditional classroom settings often cannot provide. In an era where Science, Technology, Engineering, and Mathematics (STEM) education drives economic growth and innovation, the ability to cultivate integrative understanding across these domains has become paramount for preparing students to address complex global challenges (Zhang & Liu, 2024).

The integration of mathematics and science has gained significant momentum in recent educational research and practice. These disciplines are naturally complementary, sharing methodological approaches, conceptual frameworks, and problem-solving strategies. However, traditional educational structures often treat them as isolated domains, creating artificial boundaries that impede students' abilities to recognize and leverage their interconnections (Verma & Verma, 2025). Middle school represents a critical period in students' educational development, as it is during these formative years that students begin to develop more sophisticated understanding of abstract concepts and their applications across disciplines (Aguirre-Muñoz et al., 2022).

Virtual laboratories provide a fertile ground for nurturing this integrative understanding by creating environments where students can explore the mathematical foundations of scientific phenomena and the scientific applications of mathematical principles. These digital platforms overcome many limitations of physical laboratories, including constraints related to safety, cost, time, and access to resources (Husnaini & Chen, 2019). Moreover, they afford opportunities for experimentation and exploration that might be impossible or impractical in traditional laboratory settings, enabling students to visualize abstract concepts, manipulate variables, and observe dynamic relationships in real-time (Ma et al., 2022).

The COVID-19 pandemic has accelerated the adoption of virtual laboratories in educational settings worldwide, as educators sought innovative ways to maintain quality instruction amid widespread school closures. This global shift toward remote and hybrid learning models has highlighted both the potential and the challenges of virtual laboratories in supporting integrative STEM education (Govender, 2023). As Qolamani (2022) states, "Distance learning approaches are indispensable in times of crisis, such as the COVID-19 Pandemic, when it comes to assisting the educational process." As educational systems continue to evolve in response to technological advancements and changing societal needs, understanding the effectiveness of virtual laboratories in developing integrative concepts between mathematics and science becomes increasingly important.

Research has demonstrated that virtual laboratories can enhance student engagement, motivation, and academic performance in STEM subjects (Papalazarou et al., 2024). However, studies specifically examining their impact on developing integrative concepts between mathematics and science remain limited, particularly in the middle school context. This gap in the literature is significant, as integrative understanding across STEM disciplines is essential for fostering the critical thinking, problem-solving, and innovation skills that students will need to navigate an increasingly complex world (Kelley & Knowles, 2016).

Integrative concepts between mathematics and science include mathematical modeling, data analysis and interpretation, spatial reasoning, proportional relationships, and systems thinking. These concepts serve as intellectual bridges that enable students to transfer knowledge and skills across disciplinary boundaries, deepening their understanding of both domains and enhancing their ability to apply this knowledge in novel contexts (Lumabit & Sagge, 2023). By providing structured opportunities for students to engage with these integrative concepts through hands-on exploration and discovery, virtual laboratories may offer a promising approach to strengthen connections between mathematics and science learning.

The Middle East educational context presents unique opportunities and challenges for implementing innovative educational approaches like virtual laboratories. Countries in this region are increasingly investing in educational technology as part of broader initiatives to develop knowledge-based economies and equip students with 21st-century skills (Teo et al., 2014). However, disparities in digital infrastructure, pedagogical traditions, and resource availability influence how these technologies are integrated into classroom practice. Understanding the effectiveness of virtual laboratories in developing integrative concepts within this specific educational and cultural context can inform both local policy and international educational research.

Several previous studies have explored the effectiveness of virtual laboratories within specific subject domains. Sypsas et al. (2025) investigated the use of Onlabs, a 3D virtual reality biology lab, and found improvements in students' engagement and understanding of biological concepts, though the study remained discipline-specific. Similarly, Papalazarou et al. (2024) compared physical and virtual inquiry-based experiments and concluded that virtual labs could be just as, if not more, effective than traditional labs in enhancing science learning outcomes and student attitudes. However, both studies focused solely on science, without exploring interdisciplinary applications. Lumabit and Sagge (2023) focused on mathematics, integrating virtual labs into an inquiry-based module, which improved students' higher-order thinking and mathematical modeling skills. Nonetheless, the study was limited to mathematics and did not address integration with science or shared conceptual development.

Other studies have also demonstrated the benefits of virtual laboratories in science education. Husnaini and Chen (2019) showed that guided inquiry in both virtual and physical labs improved conceptual understanding and inquiry performance in science classes, but did not explore cross-disciplinary impacts. Zacharia et al. (2008) found that virtual manipulatives could enhance students' understanding of physics concepts like heat and temperature, though the study was confined to a single scientific topic. Verma and Verma (2025) reviewed innovative virtual lab practices in science education and highlighted their pedagogical value, accessibility, and interactivity. However, like the others, their review was limited to natural sciences and did not address how virtual labs might foster integrative understanding across mathematics and science. Collectively, these studies underscore the promise of virtual labs while revealing a clear gap in research on their interdisciplinary potential specifically the integration of mathematics and science concepts.

While all six reviewed studies affirm the effectiveness of virtual laboratories in enhancing subject-specific learning outcomes—predominantly in science or mathematics none explicitly addressed the development of integrative concepts bridging mathematics and science. Most research either focused on a single subject domain or analyzed student outcomes without examining cross-disciplinary conceptual growth. Furthermore, few studies utilized experimental designs with multiple groups or constructed instruments specifically targeting integrative conceptual understanding.

The present research is among the first to experimentally assess the impact of virtual laboratories on the development of integrative concepts between mathematics and science among middle school students. It distinguishes itself by employing a three-group experimental design (mathematics virtual lab, science virtual lab, and traditional instruction), a standardized test of integrative concepts, and a focus on the middle school context in Iraq. By addressing a critical gap in the literature, this study advances our understanding of how virtual laboratories can foster interdisciplinary STEM learning and offers actionable recommendations for curriculum design, teacher professional development, and educational technology integration.

RESEARCH METHOD

This section details the procedures undertaken by the researchers, beginning with selecting an appropriate experimental design, defining the research population and sample, ensuring equivalence between the three groups (first experimental, second experimental, and control), preparing teaching plans for the groups, developing research instruments, and selecting appropriate statistical methods as follows:

The researchers employed the experimental methodology in implementing the experiment, as it was most compatible with the research objectives and hypotheses. The researchers sought to identify the effectiveness of the independent variable (virtual laboratories) on the dependent variable (development of integrative concepts between mathematics and science) in the research sample.

The experimental design represents the proper structure and appropriate strategy that controls the research and leads to reliable results in verifying research objectives and hypotheses. The researchers adopted the equivalent groups experimental design, as expressed in table (1):

Table 1, Distribution of Experimental Design

Research Groups	Independent Variable	Dependent Variable
First Experimental	Teaching mathematics using virtual laboratories	Development of integrative concepts between mathematics and science
Second Experimental	Teaching science using virtual laboratories	
Control	Traditional method	

The current research population was determined to include all eighth-grade students, totaling 4,514 male and female students in basic education schools affiliated with the Mosul Education Directorate in Duhok Governorate, distributed across 6 basic schools for the academic year (2024-2025). A random sample of 83 male and female students was selected from the research population. They were purposively selected from Ghanem Hamoudat School due to the availability of virtual laboratories (specialized classrooms for teaching each subject) for the eighth grade to represent the two experimental research groups, and Nineveh School to represent the control group. The researchers randomly distributed students from the academic sections to the three research groups. Section (B), consisting of 24 students, represented the first experimental group, and Section (A), consisting of 31 students, represented the second experimental group from Ghanem Hamoudat School. Section (D), consisting of 28 students, represented the control group from Nineveh School, after excluding 4 students from the control group for having prior experience, as shown in Table 1.

Table 2, Distribution of Research Sample Students

Section	Group	Teaching Method	Number of Students Before Exclusion	Number of Repeating Students	Number of Students After Exclusion
B	First Experimental	Teaching mathematics using virtual laboratories	24	-----	24
A	Second Experimental	Teaching science using virtual laboratories	31	-----	31
D	Control	Traditional method	32	4	28
Total			87	4	83

The researchers ensured statistical equivalence among the three research groups in several variables that might affect the experiment results. These variables were:

1. Chronological Age, Students' ages were calculated in months until (1/10/2024). The mean for the first experimental group was (159.31), for the second experimental group (156.22), and for the control group (157.19).
2. Science and Mathematics Grades from the Previous Year, The achievement scores for science and mathematics subjects from the previous year were used. For science, the mean for the first experimental group was (71.02), for the second experimental group (70.51), and for the control group (68.91). The t-value for the difference between the three groups was (1.004). For mathematics, the mean for the first experimental group was (74.03), for the second experimental group (72.15), and for the control group (69.78).
3. Previous General Average, The researchers relied on the general average for each student from the previous year. The mean for the first experimental group was (75.12), for the second experimental group (77.06), and for the control group (70.19). For mathematics, the mean for the first experimental group was (73.82), for the second experimental group (76.10), and for the control group (70.72).
4. Pre-test of Integrative Concepts, The integrative concepts test was applied on (18/10/2024). The mean for the first experimental group was (10.350), for the second experimental group (12.109), and for the control group (11.921).
5. Intelligence Quotient, Raven's Colored Progressive Matrices Test (CPM), standardized for the Arab environment, was applied to measure the intelligence of the research groups. The mean for the first experimental group was (41.24), for the second experimental group (44.75), and for the control group (41.61). To statistically verify the equivalence of the three groups in these variables, the researchers applied the One-Way Analysis of Variance (ANOVA) test to compare the means of the three groups

for the research variables. The results showed (0.395-0.993-1.726-1.294-0.135-1.385-0.439), all of which are less than the tabulated value of (3.112) at a significance level of (0.05) and degrees of freedom (2). This means there is no statistically significant difference between the means of the three research groups for each variable, thus the groups are considered equivalent in the studied variables.

6. Parents' Educational Level, The parents' educational level was divided according to the type of educational certificate, and the three groups were compared individually using the chi-square test. The calculated chi-square values for the father and mother variables were (0.569-0.273), which are less than the tabulated chi-square value of (12.59) at (0.05). This means there is no statistically significant difference in the educational level of parents among the members of the three research groups, indicating that the groups are equivalent in the variables of the father's and mother's educational level.

To achieve the research objectives and test its hypotheses, preparing a number of requirements was necessary, including:

1. Analysis of Scientific Material (Content), The content of the scientific material includes all topics scheduled for teaching in the eighth grade for science and mathematics subjects. It included chapters (first, second, and third) from the textbook for teaching mathematics and science subjects for the first semester of the academic year (2024-2025). The researchers adhered to those items that would be taught to the research groups later.
2. Formulation of Behavioral Objectives, Based on the content, the researchers formulated behavioral objectives intended to be achieved during the first semester. They prepared (63) behavioral objectives for mathematics and (59) behavioral objectives for science based on Bloom's taxonomy (remembering, understanding, application). The behavioral objectives were then presented to a group of arbitrators and specialists in education and methods of teaching mathematics and science to solicit their opinions on the correctness of behavioral objective formulation and the appropriateness of the cognitive level for each objective. The researchers adopted an agreement rate of 80% or more among the arbitrators as a criterion for the validity and appropriateness of the objective. In light of their opinions, some were modified, and based on them, daily teaching plans were prepared.
3. Preparation of Teaching Plans, In light of the scientific material scheduled for teaching to eighth-grade students and the prepared behavioral objectives, the researchers prepared (21) daily teaching plans for each group in the study for the experimental groups (first and second) according to specific steps applied inside the laboratory, which are determined by the following steps (introduction-preparation-implementation-analysis) with the main components of virtual laboratories (practical devices and equipment, computer devices, communication network, programs specific to lesson topics, simulation programs designed with multimedia technology, and programs for laboratory and student management). In addition, teaching plans were prepared according to the usual method for the control group. A model for each of the teaching plans was presented to a group of arbitrators and specialists in education and methods of teaching mathematics to indicate their opinions on their validity and suitability for the specified time, content of the material, and behavioral objectives. All agreed on their validity and comprehensiveness for the course material.

To achieve the research objective and test its hypotheses, preparation of the integrative concepts test for mathematics and science subjects was required according to the following steps:

1. Test Objective, The purpose of the test is to measure the level of acquisition of integrative concepts between mathematics and science subjects among the research sample individuals. The researchers prepared a conceptual test specific to the common topics between mathematics and science subjects for eighth-grade students.
2. Identifying Common Concepts Between Mathematics and Science Subjects, The researchers prepared a list of the main common concepts between mathematics and science subjects in general, which represented (10) common concepts. From these concepts, (6) common concepts for the eighth grade were selected, which are: (mathematical models, relationships, probability and statistics, graphical representation, equations, units and conversions).
3. Formulation of Behavioral Objectives, The researchers relied on the main concepts to be included in the concept acquisition test, distributed across levels (definition, discrimination, application). Based on these, test items were constructed and presented to a group of arbitrators and specialists in education and methods of teaching mathematics and science. The researchers adopted an agreement rate of (80%) from their opinions for acceptance, and all concepts achieved this rate.
4. Preparation of Test Items, The researchers prepared test items consisting of (6) main and sub-integrative concepts; for each concept, (3) test items measuring the three concept acquisition processes (definition-discrimination-application). The items were chosen according to the type of multiple-choice and matching tests. The test consisted of three groups of questions as follows:
   a. First Group, Consisted of (6) items of the matching type in measuring the definition of the concept.
   b. Second Group, Consisted of (6) items of the multiple-choice type in discriminating the example from examples or through drawings for the concept.
   c. Third Group, Consisted of (6) items of the multiple-choice type in measuring the application of the concept.
5. Test Validity, To ensure face validity, the researchers presented the test, its instructions, and the model answer to a committee of arbitrators and experts with experience in the field of teaching methods for mathematics and science to judge the validity of the items and their suitability for the requirements of the research sample. The researchers adopted an agreement rate of (80%) or more to accept the validity of each test item. In light of the observations they made, all test items received an acceptable rate, with some items linguistically reformulated, thus verifying the validity of the test.
6. Statistical Analysis of Test Items, To verify the psychometric properties of the test and identify the clarity of its instructions, the test was applied to a pilot sample of (100) eighth-grade students. The clarity of the test was confirmed, and the time taken to answer the test items was between (30-35) minutes. The researchers then statistically analyzed the test items to detect weak items and work on reformulating or deleting them in terms of their ease, difficulty, discrimination, and effectiveness of alternatives, as well as calculating reliability. This was done after arranging the scores in descending order and then dividing them into upper and lower groups at a rate of (27%), with 27 students in each group. The ease coefficients for each test item were calculated, ranging between (0.39-0.64), and discrimination coefficients ranging

between (0.29-0.57), which are within the acceptable range. Regarding the effectiveness of alternatives, the researchers analyzed the responses of the pilot sample individuals to the objective items only at the example (discrimination) to verify the effectiveness of the wrong alternatives and their application. The calculated rates for the alternatives for all items indicated that they were negative and less than (0.05), meaning that all distractors were good, necessitating keeping them as they are without change.

7. Test Reliability, To verify the reliability of the test, the researchers adopted the Kuder-Richardson-20 formula after applying it to the pilot sample. The reliability coefficient was (0.81), which is a good reliability coefficient that can be relied upon. Thus, the test in its final form was ready for application, consisting of (18) items distributed equally across three concept elements (definition-discrimination-application).
8. Test Scoring, To give a numerical characteristic to the responses of the research groups on the test and in light of the correction key, the researchers gave a score of (1) for the correct answer and (zero) for the wrong answer. The omitted item was treated as a wrong answer. Thus, the total score for the mathematical concepts test ranged between (0-18), with a hypothetical mean of (9) scores.

After completing the requirements for conducting the experiment, the mathematics and science teachers in the school taught the three groups to avoid the effect of changing the subject teacher. In teaching the two experimental groups, the steps of teaching using virtual laboratories were used. The laboratory was organized using the learning cycle determined by the following steps (introduction-preparation-implementation-analysis), which represent (presenting the lesson through the smart board-presenting the lesson on computer devices-conducting calculations and experiments inside the laboratory-providing an interactive environment for practical learning and application of algorithms-improving students' abilities in analysis and design-using tangible materials to learn mathematical and scientific concepts) as follows:

1. Teaching the First Experimental Group for Mathematics, The virtual laboratory method represents a teaching strategy where students test through equipment, drawings, screens, and computer devices to solve mathematical problems and develop concepts and skills. This method aims to give students practical experience and involve them in discovering mathematical facts through practical activities. The procedure includes providing materials, experiments, and conclusions to increase knowledge and build confidence for the student in addition to enjoying the lesson.
2. Teaching the Second Experimental Group for Science, The virtual laboratory method represents a teaching strategy where students test through equipment, drawings, screens, and computer devices to develop scientific concepts, formulate hypotheses, analyze data, and draw conclusions, enhancing scientific thinking capabilities.
3. Teaching the Control Group. The traditional method according to the teacher's guide distributed in basic education schools. The experiment lasted a full semester at a rate of (5) lessons per week, starting from (15/10/2024) until (14/12/2024), according to the teaching plans prepared for each group.

After completing the teaching of the academic content, the integrative concepts test was applied to the students of the three research groups on (17-18/12/2024). The researchers clarified the test instructions and how to answer it, and directed students not to leave any item unanswered.

The researchers used a number of statistical methods in data processing, including (ease coefficient, discrimination formula, chi-square test, Kuder-Richardson-20 formula, one-way analysis of variance, Scheffe's test for post-comparisons). The SPSS statistical package was utilized.

RESEARCH RESULTS AND DISCUSSION

RESEARCH RESULTS

A. First Main Hypothesis

There is no statistically significant difference at a significance level of (0.05) between the mean scores of the first experimental group that studies mathematics using virtual laboratories, students of the second experimental group that studies general science using virtual laboratories, and students of the control group that studies by (traditional method) in the post-test of integrative concepts.

To test this hypothesis, the arithmetic means and standard deviations of students' scores in the three groups on the integrative concepts test were calculated, as shown in Table 3.

Table 3, Arithmetic Mean and Standard Deviation for the Post-test of Integrative Concepts for the Three Research Groups

Group	Number of Students	Arithmetic Mean	Standard Deviation	Standard Error
First Experimental	24	14.95	2.215	0.452
Second Experimental	31	15.13	2.783	0.500
Control	28	12.79	2.348	0.444
Total	83	14.29	2.823	0.310

Table 3 shows apparent differences between the mean scores of the three groups in the post-test of integrative concepts. To determine whether these differences are statistically significant, One-Way Analysis of Variance (ANOVA) was used.

Table 4, Results of One-Way Analysis of Variance for the Scores of the Three Groups in the Post-test of Integrative Concepts and Effect Size Indicator

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Sum of Squares	F Value		Significance Level at 0.05	Effect Size (η^2)	Effect Size Interpretation
				Calculated	Tabulated			
Between Groups	216.583	2	108.292	16.748	3.111	Statistically Significant	0.295	Large
Within Groups	517.032	80	6.463					
Total	733.615	82						

The results of the analysis of variance in Table (3) show that the calculated F value was (16.748), which is greater than the tabulated F value of (3.111) at degrees of freedom (2, 80) and a significance level of (0.05). This indicates statistically significant differences between the mean scores of the three groups in the post-test of integrative concepts. The effect size indicator (η^2) shows a value of 0.295, which indicates a large effect size according to Cohen's criteria, confirming the educational importance of the recorded statistical differences. Based on this, the main null hypothesis is rejected, and the alternative hypothesis is accepted.

1. First Sub-Hypothesis

   There are no statistically significant differences at a level of (0.05) between the mean scores of the first experimental group that studies mathematics using virtual laboratories and the mean scores of students of the second experimental group that studies science using virtual laboratories in the post-test of integrative concepts.

Table 5, Results of Scheffe's Test for Comparison Between the Mean Scores of the First and Second Experimental Groups in the Post-test of Integrative Concepts and Effect Size Indicator

Variable	Group	Sample	Arithmetic Mean	Standard Deviation	Scheffe Value		Significance Level at 0.05	Effect Size (d)	Effect Size Interpretation
					Calculated	Tabulated			
Integrative Concepts Test	First Experimental	24	14.95	2.215	0.843	6.222	Not Statistically Significant	0.07	Very Weak
	Second Experimental	31	15.13	2.783					

Table 5 shows that the calculated Scheffe value for the comparison between the first and second experimental groups was (0.843), which is less than the tabulated Scheffe value of (6.222) at degrees of freedom (2, 80) and a significance level of (0.05), indicating no statistically significant difference between the mean scores of the two groups. The very weak effect size (d = 0.07) confirms that the difference between the groups has no educational or practical importance. Thus, the first sub-null hypothesis is accepted.

2. Second Sub-Hypothesis

   There are no statistically significant differences at a level of (0.05) between the mean scores of the first experimental group that studies mathematics using virtual laboratories and the mean scores of students of the control group that studies by (traditional method) in the post-test of integrative concepts.

Table 6, Results of Scheffe's Test for Comparison Between the Mean Scores of the First Experimental Group and the Control Group in the Post-test of Integrative Concepts and Effect Size Indicator

Variable	Group	Sample	Arithmetic Mean	Standard Deviation	Scheffe Value		Significance Level at 0.05	Effect Size (d)	Effect Size Interpretation
					Calculated	Tabulated			
Integrative Concepts Test	First Experimental	24	14.95	2.215	10.458	6.222	Statistically Significant	0.96	Large
	Control	28	12.79	2.348					

Table 6 shows that the calculated Scheffe value for the comparison between the first experimental group and the control group was (10.458), which is greater than the tabulated Scheffe value of (6.222) at degrees of freedom (2, 80) and a significance level of (0.05), indicating a statistically significant difference between the mean scores of the two groups in favor of the first experimental group that studied mathematics using virtual laboratories. This result is supported by the large effect size (d = 0.96), confirming the educational and practical importance of the statistical differences. Thus, the second sub-null hypothesis is rejected, and the alternative hypothesis is accepted.

2. Third Sub-Hypothesis

There are no statistically significant differences at a level of (0.05) between the mean scores of the second experimental group that studies science using virtual laboratories and the mean scores of students of the control group that studies by (traditional method) in the post-test of integrative concepts.

Table 7, Results of Scheffe's Test for Comparison Between the Mean Scores of the Second Experimental Group and the Control Group in the Post-test of Integrative Concepts and Effect Size Indicator

Variable	Group	Sample	Arithmetic Mean	Standard Deviation	Scheffe Value		Significance Level at 0.05	Effect Size (d)	Effect Size Interpretation
					Calculated	Tabulated			
Integrative Concepts Test	Second Experimental	31	15.13	2.783	12.982	6.222	Statistically Significant	0.91	Large
	Control	28	12.79	2.348					

Table 7 shows that the calculated Scheffe value for the comparison between the second experimental group and the control group was (12.982), which is greater than the tabulated Scheffe value of (6.222) at degrees of freedom (2, 80) and a significance level of (0.05), indicating a statistically significant difference between the mean scores of the two groups in favor of the second experimental group that studied science using virtual laboratories. This result is supported by the large effect size (d = 0.91), confirming the educational and practical importance of the recorded statistical differences. Thus, the third sub-null hypothesis is rejected, and the alternative hypothesis is accepted.

B. Second Main Hypothesis

There is no statistically significant difference at a significance level of (0.05) between the mean scores of integrative concepts development in the pre-test and post-test among students of the first experimental group who study mathematics using virtual laboratories and the second experimental group who study science using virtual laboratories.

To verify this hypothesis, the paired samples t-test was used between the first and second experimental groups, as it is the most appropriate for comparing the performance of the same sample before and after the experimental intervention. The effect size (Cohen's d) was also calculated to indicate the importance of the change that occurred, which is an indicator of the effectiveness of using virtual laboratories in developing integrative concepts between mathematics and science subjects.

Table 8, Results of Paired Samples t-test and Effect Size Analysis for Differences Between Pre-test and Post-test in the Integrative Concepts Test

Group	Number of Students	Mean		Standard Deviation of Difference	t Value		Degrees of Freedom at (0.05)	Statistical Significance	Effect Size (Cohen's d)	Effect Size Interpretation
		Pre	Post		Calculated	Tabulated				
First Experimental	24	10.35	14.95	2.40	7.29	2.069	23	Significant	1.92	Very Large
Second Experimental	31	12.11	15.13	2.12	7.82	2.042	30	Significant	1.42	Large

It is clear from Table 8 that both the first and second experimental groups achieved statistically significant differences between the pre-test and post-test mean scores. The first experimental group recorded a pre-test mean of 10.35 and a post-test mean of 14.95 with a calculated t-value of 7.29, degrees of freedom 23, and a tabulated t-value of 2.069 (statistically significant). The second experimental group recorded a pre-test mean of 12.11 and a post-test mean of 15.13 with a calculated t-value of 7.82, degrees of freedom 30, and a tabulated t-value of 2.042 (statistically significant), indicating a clear effect of virtual laboratories in developing integrative concepts. The results of the effect size (Cohen's d) showed that the effect was very large in the first experimental group (1.92) and large in the second experimental group (1.42), confirming the effectiveness of the teaching method based on virtual laboratories. Based on this, the second null hypothesis is rejected, and the alternative hypothesis is accepted, which states that there are statistically significant differences between the mean scores of the pre-test and post-test of integrative concepts among students of the two experimental groups.

DISCUSSIONS

The results of the study showed the effectiveness of virtual laboratories in improving students' understanding of integrative concepts between mathematics and science. The results of the test of the first main hypothesis indicated the existence of statistically significant differences between the three groups in the post-test of integrative concepts, where the main null hypothesis was rejected, confirming a clear effect of the teaching method used in developing integrative concepts among students. The large effect size confirmed the educational importance of these differences.

When looking at the results of the pairwise comparisons between the groups using Scheffe's test, we find that there are no statistically significant differences between the first experimental group that studied mathematics using virtual laboratories and the second experimental group that studied science using virtual laboratories. The very weak effect size confirmed this result. This result can be explained by the fact that using virtual laboratories in teaching both subjects has a similar positive effect on developing integrative concepts, reflecting the strength and effectiveness of this educational tool regardless of the targeted academic subject. The use of virtual laboratories helps present abstract concepts in a tangible and concrete form, making it easier for students to comprehend them and recognize the relationships between them. These laboratories also allow for repeating experiments and practical applications without time or spatial constraints, which enhances self-learning and continuous learning opportunities for students.

The results showed statistically significant differences between the first experimental group that studied mathematics using virtual laboratories and the control group that studied using the traditional method, in favor of the first experimental group. The large effect size supported this result, confirming its educational and practical importance. This result can be attributed to the fact that virtual laboratories provide an environment rich in visual and auditory stimuli that address various senses and suit diverse learning styles of students. They also help embody abstract mathematical concepts and represent them visually, making them easier to understand and comprehend. Additionally, virtual laboratories allow students to control experiment variables and observe their results directly, helping to develop scientific thinking skills and mathematical reasoning. In this interactive environment, the student's role changes from a passive receiver of information to an active participant in building knowledge, which aligns with modern educational theories that emphasize the importance of active learning and knowledge construction.

The results also showed statistically significant differences between the second experimental group that studied science using virtual laboratories and the control group, in favor of the second experimental group. The large effect size confirmed this result and its importance from an educational perspective. This result can be explained by the fact that virtual laboratories allow students the opportunity to conduct scientific experiments that may be dangerous, costly, or unavailable in traditional laboratories, expanding their perceptions and enriching their educational experiences. They also help develop observation, analysis, and inference skills, which are fundamental skills in understanding science. Additionally, virtual laboratories help link scientific concepts to their applications in real life, making learning more meaningful and lasting. In this stimulating environment, students' curiosity and passion for science increase, positively reflecting on their academic achievement and understanding of scientific concepts.

The results of the test of the second main hypothesis indicated statistically significant differences between the pre-test and post-test for the first and second experimental groups. This result was confirmed by the effect size values, which were very large in the first experimental group and large in the second experimental group. This result can be explained by the fact that virtual laboratories provide an interactive learning environment that gives students the opportunity to explore and experiment on their own, helping them understand the mutual relationships between mathematical and scientific concepts more deeply and clearly. This learning environment also takes into account individual differences among students and allows them to learn according to their own abilities and pace, which increases their motivation toward learning and makes the educational process more enjoyable and attractive.

The superiority of the two experimental groups over the control group confirms the effectiveness of virtual laboratories in developing integrative concepts between mathematics and science. This effectiveness can be attributed to several reasons, including that virtual laboratories help transcend the boundaries between different academic subjects, allowing students to see knowledge as an integrated whole rather than separate parts. They also help develop higher-order thinking skills such as analysis, synthesis, and evaluation, which are necessary skills for understanding the mutual relationships between different concepts. Additionally, virtual laboratories provide immediate feedback to students, helping them correct their mistakes and adjust their learning path continuously.

It is also worth noting that virtual laboratories align with the requirements of the digital age and respond to the interests of the current generation of students who grew up in the age of technology and prefer to use it in various aspects of their lives, including education. This explains the higher level of motivation and participation among students of the two experimental groups compared to students of the control group. Virtual laboratories also help overcome some challenges facing traditional education such as limited time and resources, as students can use them at any time and from any place, making them effective tools for continuous and self-learning.

The results of this study are consistent with the study of Zacharia et al. (2008), which confirmed that using virtual laboratories alongside real laboratories enhances students' understanding of scientific concepts related to heat and temperature. They also agree with the results of Sypsas et al. (2025), which showed that virtual laboratories provide unique educational advantages that complement real laboratories and help students link theoretical concepts to real phenomena. They are also consistent with the study of Wang & Zou (2025), which revealed the positive effect of digital games and simulations in enhancing learning and developing higher-order thinking skills. They also align with the results of Makransky et al. (2016), which showed the effectiveness of virtual simulation in improving basic laboratory skills and developing necessary non-cognitive skills among students.

The positive results shown by this study are consistent with modern global trends in education, which emphasize the importance of employing technology in the educational process and the necessity of integrating and connecting knowledge. They also confirm the role of the teacher as a guide and mentor to the educational process, designing and organizing the learning environment in a way that ensures achieving the desired educational goals. Perhaps one of the most prominent aspects these results point to is the necessity of reconsidering traditional teaching methods and searching for modern teaching strategies and tools that suit the requirements and skills of the twenty-first century.

Although this study focused on the effect of virtual laboratories on developing integrative concepts between mathematics and science, its results open the field for future studies addressing the effect of these laboratories on developing other aspects such as attitudes toward learning, creative thinking skills, and problem-solving ability. Research can also be conducted on the possibility of employing these laboratories in different educational stages and other academic subjects. It is also important to study the factors that affect the effectiveness of these laboratories such as learner characteristics, teacher competencies, and the nature of educational content.

In light of the results of this study, it can be said that virtual laboratories represent a qualitative addition to the educational process, helping to overcome some challenges facing traditional education and providing better opportunities for active and effective learning. Therefore, it is necessary to provide the infrastructure needed to employ these laboratories in schools, train teachers to use them effectively, and develop educational content that suits their multiple capabilities. Students should also be encouraged to use these laboratories not only inside the school but also outside it, enhancing the principle of continuous and self-learning.

CONCLUSIONS

Based on the findings of this research, which demonstrated the positive impact of virtual laboratories on developing integrative concepts between mathematics and science among eighth-grade students, several conclusions, recommendations, and suggestions can be formulated. The study clearly indicated that virtual laboratories provide an effective educational environment that enhances students' understanding of the interconnections between mathematical and scientific concepts, promotes active learning, and develops higher-order thinking skills. Both mathematics and science virtual laboratories showed comparable effectiveness in developing integrative concepts, suggesting that this educational approach can be successfully implemented across different STEM disciplines. Moreover, the significant improvements observed in both experimental groups compared to their pre-test scores and to the control group highlight the transformative potential of virtual laboratories in middle school education. These findings align with contemporary educational theories that emphasize the importance of technology integration, constructivist learning approaches, and interdisciplinary connections in preparing students for the challenges of the 21st century. Based on these conclusions, it is recommended that educational institutions invest in the infrastructure necessary for implementing virtual laboratories, provide comprehensive professional development for teachers to effectively utilize these technologies, develop curriculum materials that explicitly highlight the integrative concepts between mathematics and science, and create opportunities for students to access virtual laboratories both inside and outside the classroom. Future research should explore the long-term effects of virtual laboratory experiences on students' academic trajectories, investigate the impact of virtual laboratories on diverse student populations, examine the optimal balance between virtual and physical laboratory experiences, and develop standardized assessment tools for measuring integrative conceptual understanding across STEM disciplines. By embracing virtual laboratories as tools for developing integrative concepts, educators can create more engaging, effective, and equitable learning experiences that prepare students for success in an increasingly interconnected and technology-driven world.

REFERENCES

Aguirre-Muñoz, Z., Dang, B., & Garro, E. S. L. (2022). Impact of integrated science and mathematics instruction on middle school science and mathematics achievement. In Advances in research in STEM education. IntechOpen.

Artigue, M., & Blomhøj, M. (2013). Conceptualizing inquiry-based education in mathematics. Zdm, 45, 797-810.

Berezi, I. U. (2025). Virtual Learning Environment: Redefining Higher Educational Delivery for Efficiency and Accessibility. International Journal of Educational Management, Rivers State University., 1(1), 451-467.

Elmoazen, R., Saqr, M., Khalil, M., & Wasson, B. (2023). Learning analytics in virtual laboratories: a systematic literature review of empirical research. Smart Learning Environments, 10(1), 23.

Goudsouzian, L. K., Riola, P., Ruggles, K., Gupta, P., & Mondoux, M. A. (2018). Integrating cell and molecular biology concepts: Comparing learning gains and self-efficacy in corresponding live and virtual undergraduate laboratory experiences. Biochemistry and Molecular Biology Education, 46(4), 361-372.

Husnaini, S. J., & Chen, S. (2019). Effects of guided inquiry virtual and physical laboratories on conceptual understanding, inquiry performance, scientific inquiry self-efficacy, and enjoyment. Physical Review Physics Education Research, 15(1), 010119.

Husnaini, S. J., & Chen, S. (2019). Effects of guided inquiry virtual and physical laboratories on conceptual understanding, inquiry performance, scientific inquiry self-efficacy, and enjoyment. Physical Review Physics Education Research, 15(1), 010119.

Jatmiko, B., Sunarti, T., Prahani, B. K., Hariyono, E., Wibowo, F. C., Mahtari, S., & Asy'ari, M. (2021, November). Critical thinking skills on physics learning during COVID-19 pandemic: A bibliometric analysis using VOSViewer. In Journal of Physics: Conference Series (Vol. 2110, No. 1, p. 012020). IOP Publishing.

Joswick, C., & Hulings, M. (2024). A systematic review of BSCS 5E instructional model evidence. International Journal of Science and Mathematics Education, 22(1), 167-188.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. International Journal of STEM education, 3, 1-11.

Kolil, V. K., & Achuthan, K. (2023). Longitudinal study of teacher acceptance of mobile virtual labs. Education and Information Technologies, 28(7), 7763-7796.

Li, Y., Liang, M., Preissing, J., Bachl, N., Dutoit, M. M., Weber, T., ... & Hussmann, H. (2022, February). A meta-analysis of tangible learning studies from the tei conference. In Proceedings of the sixteenth international conference on tangible, embedded, and embodied interaction (pp. 1-17).

Lin, L., Shadiev, R., Hwang, W. Y., & Shen, S. (2020). From knowledge and skills to digital works: An application of design thinking in the information technology course. Thinking Skills and Creativity, 36, 100646.

Lumabit, A. M. C., & Sagge Jr, R. G. (2023). An Inquiry-Based Learning Module for General Mathematics: Its' Development and Evaluation. International Journal of Multidisciplinary: Applied Business and Education Research, 4(8), 2749-2756.

Lumabit, A. M. C., & Sagge Jr, R. G. (2023). An Inquiry-Based Learning Module for General Mathematics: Its' Development and Evaluation. International Journal of Multidisciplinary: Applied Business and Education Research, 4(8), 2749-2756.

Makransky, G., Thisgaard, M. W., & Gadegaard, H. (2016). Virtual simulations as preparation for lab exercises: Assessing learning of key laboratory skills in microbiology and improvement of essential non-cognitive skills. PloS one, 11(6), e0155895.

May, D., Alves, G. R., Kist, A. A., & Zvacek, S. M. (2023). Online laboratories in engineering education research and practice. In International handbook of engineering education research (pp. 525-552). Routledge.

Papalazarou, N., Lefkos, I., & Fachantidis, N. (2024). The effect of physical and virtual inquiry-based experiments on students' attitudes and learning. Journal of Science Education and Technology, 33(3), 349-364.

Papalazarou, N., Lefkos, I., & Fachantidis, N. (2024). The effect of physical and virtual inquiry-based experiments on students' attitudes and learning. Journal of Science Education and Technology, 33(3), 349-364.

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V. M., & Jovanović, K. (2016). Virtual laboratories for education in science, technology, and engineering: A review. Computers & Education, 95, 309-327.

Qolamani, K. (2022). Effectiveness of Online Teaching & Learning during Covid-19 Pandemic-Social Studies Students' Perspective. Humanities Journal of University of Zakho, 10(3), 856-862.

Reginald, G. (2023). Teaching and learning using virtual labs: Investigating the effects on students' self-regulation. Cogent Education, 10(1), 2172308.

Soliman, M., Pesyridis, A., Dalaymani-Zad, D., Gronfula, M., & Kourmpetis, M. (2021). The application of virtual reality in engineering education. Applied Sciences, 11(6), 2879.

Sypsas, A., Paxinou, E., Zafeiropoulos, V., & Kalles, D. (2025). Virtual Laboratories in STEM Education: A Focus on Onlabs, a 3D Virtual Reality Biology Laboratory.

In Online Laboratories in Engineering and Technology Education: State of the Art and Trends for the Future (pp. 323-337). Cham: Springer Nature Switzerland.

Sypsas, A., Paxinou, E., Zafeiropoulos, V., & Kalles, D. (2025). Virtual Laboratories in STEM Education: A Focus on Onlabs, a 3D Virtual Reality Biology Laboratory. In Online Laboratories in Engineering and Technology Education: State of the Art and Trends for the Future (pp. 323-337). Cham: Springer Nature Switzerland.

Talib, S., Alias, B. S., Matore, M. E. E. M., & Abdullah, A. H. (2025). Empowering STEM education through the role of principals: a systematic literature review. Journal of Education and Learning (EduLearn), 19(1), 570-578.

Teo, T. W., Tan, K. C. D., Yan, Y. K., Teo, Y. C., & Yeo, L. W. (2014). How flip teaching supports undergraduate chemistry laboratory learning. Chemistry Education Research and Practice, 15(4), 550-567.

Tsai, C. Y., Ho, Y. C., & Nisar, H. (2021). Design and validation of a virtual chemical laboratory—An example of natural science in elementary education. Applied Sciences, 11(21), 10070.

Tuna, A., & Kacar, A. (2013). The effect of 5E learning cycle model in teaching trigonometry on students' academic achievement and the permanence of their knowledge. International Journal on new trends in education and their implications, 4(1), 73-87.

Verma, S. K., & Verma, R. K. (2025). Innovations in Virtual Labs for Teaching Natural Sciences in Secondary Education. International Journal of Sciences and Innovation Engineering, 2(1), 1-6.

Verma, S. K., & Verma, R. K. (2025). Innovations in Virtual Labs for Teaching Natural Sciences in Secondary Education. International Journal of Sciences and Innovation Engineering, 2(1), 1-6.

Wang, X., & Zou, F. (2025). A Systematic Literature Review on Educational Game Design Research: Based on Bibliometric and Content Analysis (2013–2023). In International Conference on Human-Computer Interaction (pp. 175-194). Springer, Cham.

Zacharia, Z. C., Olympiou, G., & Papaevripidou, M. (2008). Effects of experimenting with physical and virtual manipulatives on students' conceptual understanding in heat and temperature. Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 45(9), 1021-1035.

Zacharia, Z. C., Olympiou, G., & Papaevripidou, M. (2008). Effects of experimenting with physical and virtual manipulatives on students' conceptual understanding in heat and temperature. Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 45(9), 1021-1035.

Zhang, N., & Liu, Y. (2024, January). Design and implementation of virtual laboratories for higher education sustainability: a case study of Nankai University. In Frontiers in Education (Vol. 8, p. 1322263). Frontiers Media SA.