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Revolutionizing Elementary Mathematics Education Through Virtual Labs

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Abstract

This study aimed to investigate the effectiveness of the virtual lab in teaching mathematics and its impact on the development of mathematical power and tendency towards mathematics among fourth-grade students in the Kingdom of Bahrain. To achieve the study's objectives, a quasi-experimental approach was employed. The sample consisted of 64 randomly selected students, divided into two groups (control=31, experimental=33). The study instruments included a mathematical power test and a scale of tendency towards mathematics. The results indicated a statistically significant difference between the mean scores of the two groups in the post-test for mathematical power in favor of the experimental group. There was also a statistically significant difference between the mean scores of the two groups in the post-application for the scale of tendency towards mathematics, favoring the experimental group. Furthermore, a positive relationship was found between mathematical power and tendency towards mathematics among students in the experimental group who were taught using the virtual lab. The study recommends that the Ministry of Education in the Kingdom of Bahrain consider the importance of establishing a virtual mathematics lab in primary education due to its positive impact on students' learning. Curriculum designers are advised to reconstruct primary school mathematics curriculum to incorporate various and diverse virtual lab activities. Additionally, teacher preparation programs should emphasize equipping educators with the necessary skills to effectively utilize technology, particularly virtual laboratories, in mathematics instruction.

Keywords:

Virtual Lab in Teaching Mathematics, Mathematical Power, Tendency Towards Mathematics, Elementary Stage, Kingdom of Bahrain

Introduction

The primary education stage is considered one of the most crucial educational phases, as it plays a fundamental role in shaping students' intellectual, social, skill, and informational development. Recognizing its significance, the Kingdom of Bahrain has shown keen interest in primary education, providing various support and resources to enable it to effectively fulfill its developmental role (Jebara, 2017).

In the educational system of Bahrain, mathematics is regarded as a subject deserving substantial attention to meet the needs of the Bahraini society and achieve the vision of Bahrain 2030, aiming to produce citizens capable of contributing to the kingdom's development and enhancing its economy through the acquisition of mathematical skills and knowledge (eGovernment of Bahrain, n.d.).

Mathematics holds a distinctive position and importance due to its role as a foundational and diversified subject, encompassing more than isolated concepts, operations, and routine skills (Turgut & Turgut, 2020). At the core of this foundation lies mathematical power, defined as the maximum knowledge in mathematics that can be utilized for thinking and communication (National Council of Teachers of Mathematics [NCTM], 2000). Developing mathematical power involves enhancing students' capacity for reasoning, critical thinking, and problem-solving (Abouassar, 2003). The development of mathematical power improves students' academic achievement, indicating their mastery of the required competencies, leading to increased performance in local and international assessments (Rizk, 2012).

To foster proper development of mathematical power in students, they must be motivated to learn mathematics and reach a stage of enjoyment in the learning process, thereby satisfying their inclinations. Therefore, a positive tendency towards mathematics encourages students to engage in activities requiring mathematical skills, driven by the sense of pleasure and satisfaction during their performance. Hence, students should experience enjoyable activities to consolidate their positive inclinations toward mathematics, enabling them to progress in acquiring new skills and knowledge, especially since some mathematics topics are often perceived as abstract (Rizk, 2012).

Virtual laboratories are technological tools that support active and student-centered learning. They represent artificially created learning environments that simulate reality, allowing students to interact using electronic devices such as computers, mobile phones, tablets, or other electronic devices (Alradi, 2008). Elmaradany and Mokhtar (2011) explained that virtual environments are essential learning systems providing various services and educational tools to meet students' needs for communication and interaction with peers and educators.

In a virtual lab, mathematics lessons are modeled and presented in electronic form, conveying the intended meaning through audio, visual, and motion techniques. The characteristics of virtual laboratories, as mentioned in the study by Albasyouny et al. (2010), Abouassar (2018), and Hassn (2019), motivate their use in the teaching and learning process due to their positive impact on students' cognitive and skill development in mathematics. Therefore, the current study seeks to investigate the effectiveness of the virtual lab in mathematics on the development of mathematical power and tendency towards mathematics among primary school students.

Study problem and questions:

The awareness of the study's problem emerged through one of the researchers' experiences in teaching mathematics at the elementary level. The prevalence of traditional teaching methods and the absence of utilizing virtual lab technology was observed. Additionally, the Ministry of Education provided electronic classrooms with a set of computers sufficient for each class, but these classrooms were not utilized for employing virtual lab technology in mathematics. Furthermore, the researchers had a passion and desire to enhance teaching methods for the elementary level, aligning them with virtual laboratories to develop mathematical power and a tendency towards mathematics.

Therefore, the purpose of this study is to investigate the effectiveness of the virtual lab in teaching mathematics on the development of mathematical power and tendency towards mathematics. The research aimed to answer the following research questions:

1. What is the effectiveness of the virtual lab in teaching mathematics on the development of mathematical power among fourth-grade students in Bahrain?
2. What is the effectiveness of the virtual lab in teaching mathematics on the development of the tendency towards mathematics among fourth-grade students in Bahrain?
3. What is the relationship between mathematical power and the tendency towards mathematics among fourth-grade students in Bahrain?

Theoretical Framework & Literature Review

Virtual Lab:

The virtual lab is considered one of the modern innovations in educational technology, extending from electronic simulation systems. The virtual lab is an artificial learning environment that replaces and simulates the real world. In this virtual environment, students immerse themselves in a fictional setting, interacting with it through their senses using computer devices. The virtual lab is an extension of electronic simulation systems (Alradi, 2008). Bajpai (2012) defined it as computer software that facilitates low-cost laboratory experiments. The virtual lab assists students in conducting safe experiments without exposing them to the risks associated with real labs. It allows students to build a mental model of the experiment to easily achieve the experiment's goals, aiding in the development and mastery of mathematical and life skills (Abouassar, 2018).

The philosophy of the virtual lab is rooted in making the learning process accessible to all students, to the extent that their abilities enable them to succeed in achieving the principle of equal educational opportunities. It also provides educational opportunities for students with special needs, allowing them to work actively and sustainably. Several studies (e.g., Elsadi, 2011; Epper & Garn, 2004; Yang & Heh, 2007) have indicated that the philosophy of the virtual lab is based on several principles derived from the philosophy of virtual reality and distance education, including (1) entering the imaginary world as if it were a created reality as an alternative to the real world due to the inability to access it or due to its dangers, (2) breaking the barriers of time and place in the old education system, emphasizing the continuity of lifelong learning, (3) enhancing student learning freedom, where each student learns on their own according to their abilities and needs, (4) promoting distance education principles and relying on new educational tools and modern methods, embodying the spirit of the age and its requirements, and (5) innovating interactive scientific topics in simple and interesting ways.

The virtual lab plays a significant role in mathematics education as it helps develop students' practical skills by conducting laboratory experiments. It provides an opportunity for students to understand the principles and concepts related to the subject content accurately and deeply through the interactive environment. The virtual lab supplies students with a clear set of events in which to actively participate in the simulation experience, offering them multiple options that suit their preferences. It allows students to deal with systems that may be challenging to handle under ordinary circumstances due to high costs or concerns about safety and security. It enables each student to expand their scientific imagination and develop their innovative ideas individually. Serious play is integrated into practical practice, attracting students' interest and encouraging their participation in the learning process (Albyaty, 2006; Bajpai, 2012; Jung et al., 2006; Noufal, 2010; Stewart et al., 2006).

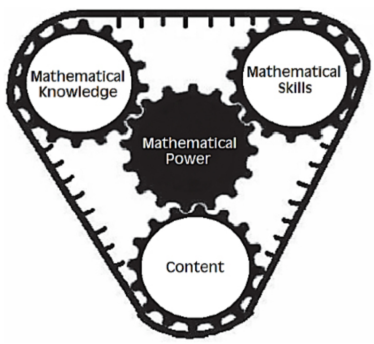
It is evident from the above that the virtual lab serves as a mediator between reality and abstraction. Through it, students can learn mathematics in its true form. The virtual lab helps students remember and learn properties, apply skills, understand concepts, and solve mathematical problems. Additionally, the virtual lab can be used as an introduction to teaching applied mathematics at the elementary level, allowing students to build mathematical models to illustrate abstract concepts and principles, conduct experiments using the scientific method for verification and proof, and ultimately verify laws and theories.

Numerous studies have attempted to test the impact of implementing the virtual lab in teaching and learning mathematics at different educational stages. The virtual lab had a positive effect on teaching the volume unit for sixth-grade students, positively influencing their cognitive and performance aspects, and increasing their academic achievement levels (Albasyouny et al., 2010). In teaching engineering and measurement to secondary school students, it improved the learning experience of various engineering concepts (Guerrero et al., 2016). It contributed to the academic development of secondary school female students by providing fun and excitement and facilitating teamwork (Al Maghamasi, 2016). It enhanced the measurement skills of spatial volumes and aesthetic perception for sixth-grade students (Hassn, 2019). It fostered motivation, independence, and improved the level of secondary school students (Moreno-Guerrero et al., 2020). It also developed the skills of students with learning difficulties (Alghanmi & Alhassani, 2020). Consequently, many studies have confirmed the positive effectiveness of the virtual lab for mathematics on various dependent variables. Thus, the virtual lab will be used as an independent variable in this study.

Mathematical Power:

Mathematical power is considered the primary standard for evaluating the quality of mathematics among students. It encompasses students' abilities in research, estimation, reasoning, creative and critical thinking, as well as the ability to formulate and solve problems (Alhasani & Al-Dulaimi, 2011). According to Qassim and Al-Saydawy (2013), mathematical power is the highest level of mathematical knowledge that a student can use in thinking and communication. It is also defined by Almuqayed (2017) as the student's ability to use mathematical knowledge in discovery, correlation, mathematical reasoning, and solving familiar and unfamiliar mathematical problems.

Figure 1:
The Mathematical Power Dimensions (Sahin & Baki, 2010)



Sahin and Baki (2010) pointed out that mathematical power has three main dimensions: mathematical content, mathematical knowledge, and mathematical skill (see Figure 1). Mathematical content includes the domains and fundamental standards of mathematics, such as numbers, arithmetic operations, algebra, and geometry (Pilten, 2010). Mathematical knowledge is the students' ability to understand and determine the role that mathematics plays in meeting their life needs (BouJaoude, 2009). Mathematical knowledge includes three capacities: conceptual knowledge, procedural knowledge, and problem-solving. Mathematical skills include three areas: mathematical communication, mathematical connection, and mathematical reasoning (Abu-Zaineh, 2017; Al-Kubaisi & Abdullah, 2015). According to Riani (2012), mathematical power is characterized by the ability to identify multiple patterns of mathematical skills (mathematical communication, mathematical connection, mathematical reasoning) and to determine sub-levels of mathematical knowledge (conceptual knowledge, procedural knowledge, problem-solving).

Given the importance of developing mathematical power in students at various stages, educational studies have attempted to find the best ways to nurture it. Many studies (Abdelwahed et al., 2022; Albashiti, 2015; Al-Haddad, 2021) have demonstrated the impact and effectiveness of employing electronic programs in improving and developing mathematical power. Abdelwahed et al. (2022) found the effectiveness of a nanotechnology-based electronic program in developing mathematical power and future thinking skills among secondary school students. Al-Haddad (2021) determined the effectiveness of electronic software for teaching mathematics in developing mathematical power for teacher-students in the College of Education. Albashiti (2015) recognized the effectiveness of a multiple intelligences-based electronic program in developing mathematical power among third-grade female students. From the above, we find that many studies have diligently tried to develop mathematical power as a dependent variable, given its importance in students' learning of mathematics. Therefore, mathematical power will be used as a dependent variable in this study.

Tendency Towards Mathematics:

Tendencies are psychological motivations acquired through the environment and experiences. Tendency can be defined as behavior that arises and manifests as a result of natural psychological needs (Al-Mosawi et al., 2015). Therefore, educators affirm that developing tendencies has become an essential educational requirement due to the significant outcomes it can demonstrate in regulating the course of the educational process and adjusting its direction. There is a correlation between tendencies and learning that gives the educational process a vital and meaningful aspect. Several recent studies have confirmed that students' positive tendencies toward the subject they are learning help them master it (Abdulhadi, 2015; Alraie, 2014; Jouda, 2013).

The definitions of tendency have varied; Alkhouli (2002) defined it as a desire arising from emotions and expressing the student's readiness to express love for a specific task. Al-Dahiri and Al-Kubaisi (2016) described it as feelings accompanying a person's attention and interest in a particular subject. Abu Gado (2020) defined it as a set of cognitive, emotional, and behavioral components related to an individual's response to a problem, topic, or situation, and the acceptance or rejection of these responses. This is the definition adopted in this study.

Teachers play a crucial role in developing students' tendency toward mathematics, transferring experiences, and motivating them. Elholy (2011) identified the teacher's role in developing students' tendencies through: (1) encouraging desired tendencies in students and nurturing them, (2) extinguishing undesirable tendencies and replacing them with desired tendencies through educational methods, (3) instilling new tendencies that were not originally present in students, such as a love for reading or writing, (4) developing human relationships with students built on respecting opinions and self-appreciation, helping reveal students' tendencies and fostering them. Abuhelal (2012) believes that for a teacher to develop a student's tendencies toward mathematics, they must consider (1) the student's needs, (2) creating a comfortable learning environment, (3) diversifying mathematical learning methods to include all learning styles, (4) conveying the idea or concept through appropriate representation, and (5) involving the student in reaching the mathematical concept.

Given the importance of developing a tendency toward mathematics in students' learning of mathematics, various studies have sought the most suitable ways to develop and improve it. Abuhelal (2012) clarified the impact of mathematical representations on acquiring concepts and a tendency toward mathematics for sixth-grade primary school students. Abdulqader (2018) demonstrated the effect of employing the numbered heads together strategy in developing visual thinking skills and a tendency toward mathematics for fourth-grade primary school students. Abuhelal (2018) affirmed the impact of entertainment-based learning on developing some thinking skills and a tendency toward mathematics in students. From the above, we find that many studies have diligently tried to develop a tendency toward mathematics as a dependent variable, given its importance and necessity in students' learning of mathematics. Therefore, the tendency toward mathematics will be used as a dependent variable in this study.

This study differs from others as it aims to study the effectiveness of the virtual lab in teaching mathematics on developing mathematical power and a tendency toward mathematics for fourth-grade students in primary school in the Kingdom of Bahrain, which has not been studied by previous studies within the researchers' knowledge boundaries.

Methodology

The current study aims to investigate the effectiveness of the virtual lab in teaching mathematics on developing mathematical power and tendency toward mathematics among fourth-grade students in primary schools in the Kingdom of Bahrain. To achieve this, a quasi-experimental design was employed, based on a two-group design. One group, considered the control group, studied the chapter "Identifying and Describing Geometric Shapes" using traditional methods, while the experimental group studied the same unit using the virtual mathematics lab. This design was used to study the impact of the independent variable on the dependent variables, with study instruments applied to both groups before and after treatment.

Research Population:

The study's population includes all individuals who are the subject of the research problem, encompassing people such as students and teachers or a group of things like books (Obeidat et al., 2020). In this study, the population consists of all fourth-grade students in Muharraq Governorate in the Kingdom of Bahrain during the second semester of the academic year 2023-2024.

Research Sample:

The study sample is a subset of the study population with its characteristics and features (Al-Adl, 2014). The sample of this study was selected randomly, facilitated by one of the researchers working as a primary school teacher in Al-Muharraq Governorate. Two groups were randomly chosen from a total of four fourth-grade groups using the random sampling method. One group represented the control group (*N* = 31), studying the chapter "Identifying and Describing Geometric Shapes" using traditional methods. The second group represented the experimental group (*N* = 33) with students studying the same unit using the virtual lab. Thus, the sample size in this study comprises (*N* = 64) fourth-grade students (see Table 1).

Table 1:
Study sample information

Group	Treatment	N
Experimental	Virtual lab	33
Control	Traditional methods	31
Total of the sample size		64

Research Variables:

The research variables were defined as follows:

Independent Variable: Virtual lab usage.

Dependent Variables: Development of mathematical power and tendency towards mathematics.

External Variables:

a. Age: To ensure the homogeneity of the study groups' ages, school records were reviewed, revealing that both groups' ages ranged from 9 to 10 years.

b. Gender: The sample consisted exclusively of male students.

c.Level of Dependent Variables in the participants: Equality in the level of mathematical power and tendency towards mathematics was verified through the pre-application of study instruments to both groups.

d.Teachers: One of the researchers served as the teacher who implemented the study with both groups to ensure educational equality.

Experimental Treatment Materials:

To achieve the study's objectives, experimental treatment materials and the following study tools were designed:

Experimental Treatment Materials: A teacher's guide for teaching according to the proposed virtual lab in the chapter "Identifying and Describing Geometric Shapes," accompanied by various in-class and out-of-class activities for students.

Instrumentation:

The researchers prepared all research instruments, including:

A. Mathematical power test on the chapter "Identifying and Describing Geometric Shapes."

B. Tendency toward mathematics scale.

C. A dedicated website for the virtual mathematics lab.

Mathematical Power Test:

Test objective: This test aims to assess the proficiency level of fourth-grade students in the three dimensions of mathematical power: communication, connections, and reasoning.

Test items: Drawing upon the literature and previous studies that focused on developing the dimensions of mathematical power, it was found that measuring the three dimensions (communication, connections, and reasoning) could be achieved by preparing a test that assesses students' conceptual, procedural, and problem-solving aspects. The test consists of 19 items, divided into two sections: one for multiple choice (13 items) and the other for essay questions (6 items), distributed across the axes of mathematical power, as illustrated in Table 2. Each multiple-choice question offers four options (a, b, c, d), while the essay questions require a comprehensive response. Correct answers in multiple-choice questions are awarded 1 point each. Essay questions are scored as follows:

0: No response or irrelevant answer.

1: Partially correct answer.

2: Fully correct answer.

Validity of the Test:

i. Face validity: The test, in its initial form, was presented to a group of curriculum and instruction specialists, as well as some mathematics teachers, to gather their opinions on the general framework of the test, test instructions, the number of test items, distribution of scores on items, inclusivity of the test for scientific content, appropriateness of questions to measure mathematical power dimensions, balance in the distribution of mathematical power dimensions among test questions, linguistic formulation of questions, scientific formulation of questions, appropriateness of questions to students' levels, diversity of questions, and clarity of ideas in test questions. Some modifications were made based on the experts' opinions, leading to adjustments in the test specifications, including the number of questions and grades for each dimension of mathematical power (see Table 3).

Pilot Study: The researchers applied the test to an experimental sample consisting of 45 students in the fourth grade (not the study sample) to calculate the psychometric properties of the mathematical power skills test.

ii. Discriminant/divergent validity: Discriminant validity was conducted on the test. The survey participants (*n* = 45) were ranked in descending order according to the total score each achieved on the mathematical power test. The top 27% of scores (12 students) and the lowest 27% of scores (also 12 students) were selected. A comparison was then made between the scores of the two groups using the Mann-Whitney U test (see Table 4).

Table 4 indicates statistically significant differences at a significance level of 0.01 between the average scores of low and high scorers on the mathematical power test. This confirms the test's validity in discriminant between performance levels in the mathematical power test among participants.

Reliability of the Test:

Test reliability refers to the extent to which the test yields nearly the same results when reapplied to the same students. The tool was applied to a survey sample of 45 students, and the reliability coefficients were calculated using the test-retest method with a time interval of 15 days (see Table 5).

Table 5 shows that all reliability coefficients for dimensions of the mathematical power test, as well as the whole test, are statistically significant at the 0.01 level. The correlation coefficient value between the total score in the two applications of the mathematical power test is 0.962, indicating a strong correlational relationship. This confirms that the test has a high level of reliability.

Difficulty index: The difficulty index is the percentage ratio of the number of students who answered the question incorrectly to the total number of correct and incorrect answers. According to Al-Huwaidi (2015), any item with a difficulty index between 0.1 and 0.9 is considered acceptable and can be included in the test. The difficulty index for the mathematical power test items is presented in Table 6.

Table 6 shows that the difficulty index for mathematical power test items range between 0.16 and 0.29. According to Al-Huwaidi (2015), any item with a difficulty index in this range is acceptable and can be included in the test.

Item discrimination: The discriminatory ability of the mathematical power test items was verified by calculating the Pearson correlation coefficient between the scores of each individual item and the dimension to which it belongs, as well as the correlations between the test dimensions themselves and the whole score of the test to which they belong (refer to Table 7).

Table 7 indicates that all items are statistically significantly correlated with their respective dimensions at significance levels of 0.05 and 0.01. This demonstrates the ability of the test items to discriminate. Correlation coefficients were also computed between the score of each dimension of the test with other dimensions and the overall score of the test (see Table 8).

Table 2:
Items of mathematical power test

Dimensions	Number of items
Mathematical communication	8 items (5 multiple choices, 3 essay)
Mathematical connection	5 items (4 multiple choices, 1 essay)
Mathematical reasoning	6 items (4 multiple choices, 2 essay)
Total	19 items

Table 3:
Specifications of the mathematical power test in the final form

Chapter	Lessons	Mathematical communication		Mathematical connection		Mathematical reasoning		# Items	# Scores
		Items	Scores	Items	Scores	Items	Scores		
Identifying and describing geometric shapes	3D shapes	2	2	2	2	1	2	5	6
	2D shapes	3	5	-	-	2	2	5	7
	Angles	1	1	2	2	-	-	3	3
	Triangles	-	-	-	-	3	4	3	4
	Quadrilaterals	2	3	1	2	-	-	3	5
Total		8	11	5	6	6	8	19 items	25 scores

Table 4:
Results of discriminant validity (Mann-Whitney U test) for mathematical power test

Mathematical power test	*n* = 12	Mean Rank	Sum of Ranks	Z	p-value
Mathematical communication	high scores	18.20	218.47	4.050	0.000
	low scores	6.70	81.00		
Mathematical connection	high scores	18.51	222.00	4.487	0 .000
	low scores	6.50	78.00		
Mathematical reasoning	high scores	18.33	219.30	4.473	0 .000
	low scores	6.79	88.00		
Total	high scores	18.50	222.00	4.452	0.000
	low scores	6.50	78.00		

Table 5:
Reliability coefficients for the mathematical power test

Dimensions	Correlation coefficients
Mathematical communication	0.913**
Mathematical connection	0.947**
Mathematical reasoning	0.851**
Total	0.962**

Note: ** Correlation is significant at 0.01 level.

Table 6:
Difficulty index for mathematical power test

Mathematical communication		Mathematical connection		Mathematical reasoning	
Item	Difficulty index	Item	Difficulty index	Item	Difficulty index
1	0.24	2	0.18	5	0.24
3	0.27	7	0.27	6	0.27
4	0.20	11	0.22	9	0.20
8	0.24	12	0.22	13	0.13
10	0.29	Essay 5	0.16	Essay 2	0.18
Essay 1	0.16			Essay 4	0.13
Essay 3	0.18				
Essay 6	0.24				

Table 7:
Pearson correlation coefficients for items of mathematical power

Mathematical communication		Mathematical connection		Mathematical reasoning	
Item	Correlation coefficient	Item	Correlation coefficient	Item	Correlation coefficient
1	0.413**	2	0.517**	5	0.450**
3	0.503**	7	0.448**	6	0.614**
4	0.482**	11	0.515**	9	0.300*
8	0.597**	12	0.358*	13	0.300*
10	0.569**	Essay 5	0.810**	Essay 2	0.679**
Essay 1	0.571**			Essay 4	0.787**
Essay 3	0.636**				
Essay 6	0.476**				

Note: * Correlation is significant at 0.05 level, and ** correlation is significant at 0.01 level.

Table 8 reveals that all dimensions of the mathematical power test are correlated with each other and with the whole test score at a statistically significant level of 0.01. This affirms that the test possesses a high ability of its items to discriminate.

Discrimination Index: The discrimination index measures the test's ability to differentiate between high-achieving and low-achieving students in the characteristic assessed by the test (Abu Nahiah, 1994). The discrimination index for each item of the test was calculated using the following equation:

$$DX = \left(\frac{H - L}{\frac{1}{2}N}\right) \times 100$$

where:
DX = Discrimination Index.
H = number of correct answers in the upper group.
L = number of correct answers in the lower group.
N = total number of individuals who attempted to answer the question in both groups.

To obtain the discrimination index for each item of the test, the researchers divided the students into two groups: an upper group consisting of the top 27% of students who scored the highest on the test and a lower group consisting of the lowest 27% of students who scored the lowest on the test. Each group contained 12 students.

Some experts suggest that the discrimination index should not be less than 25%, and the higher the percentage of the discrimination index, the better, as it enhances the item's ability to discriminate (Abu Nahiah, 1994). Table 9 illustrates the discrimination indices for each item of the test.

Table 9 shows that the discrimination indices for the test items were not less than 25%. Therefore, all items have acceptable discrimination indices, and accordingly, all items in the mathematical power test were accepted.

Tendency toward Mathematics Scale:

Scale objective: The purpose of this scale is to identify the tendency of fourth-grade students towards learning mathematics and to reveal the impact of using the virtual lab in teaching mathematics on developing the tendency towards it.

Scale items: Based on the literature and previous studies focusing on developing the tendency towards mathematics, the scale was formulated to encompass four dimensions: (tendency towards the nature of mathematics, tendency towards learning mathematics, tendency towards enjoying mathematics, tendency towards the mathematics teacher). The scale consists of 26 items distributed across the dimensions of the tendency towards mathematics, as illustrated in Table 10.

Validity of the Scale:

i. Face validity: After preparing the initial version of the scale, it was presented to a group of experts specialized in curriculum and instruction and some mathematics teachers to gather their opinions regarding adding, deleting, or modifying scale statements. The goal was to ensure the relevance of the statements to each dimension, the clarity and linguistic appropriateness of the statements for fourth-grade students, and the sufficiency and clarity of the scale instructions. Some adjustments were made to the scale statements based on the reviewers' feedback. The final scale comprised 26 statements distributed on a three points Likert scale, where the responses were Agree = 3, I don't know = 2, and Disagree = 1.

Pilot Study: The researchers applied the test to a pilot sample of 45 fourth-grade students (not part of the study sample) to calculate the psychometric properties of the scale of tendency towards mathematics.

ii. Discriminant/Divergent Validity:

Discriminative validity was assessed by ranking the survey sample individuals (n = 45) in descending order based on the scores achieved in the scale of tendency towards mathematics. The top 27% of scores (12 students) and the lowest 27% of scores (also 12 students) were selected. Finally, a comparison was made between the scores of the two groups using the Mann-Whitney U test (see Table 11).

Table 11 indicates statistically significant differences at a significance level of 0.01 between the average scores of low and high scorers on the scale of tendency towards mathematics, confirming the scale's validity in distinguishing performance levels among participants.

Reliability of the Scale:

To verify the scale's reliability, the Cronbach's alpha coefficient was calculated. The Cronbach's alpha test results were 0.784 for the scale as a whole, indicating an appropriate level of reliability for the scale.

Item discrimination: The ability of the statements of the scale to discriminate was verified by calculating the Pearson correlation coefficient between the scores of each statement of the scale and the dimension to which it belongs, as well as the correlations between the scale dimensions themselves and the whole score of the scale to which they belong (refer to Table 12).

Table 8:
Pearson correlation coefficients for dimension of mathematical power

Dimensions	Mathematical communication	Mathematical connection	Mathematical reasoning	Whole
Mathematical communication	-	0.664**	0.736**	0.938**
Mathematical connection	-	-	0.606**	0.817**
Mathematical reasoning	-	-	-	0.882**

Note: ** Correlation is significant at 0.01 level.

Table 9:
Discrimination Indices for Each Item of the Mathematical Power Test

Mathematical communication		Mathematical connection		Mathematical reasoning	
Item	DX	Item	DX	Item	DX
1	42%	2	58%	5	50%
3	58%	7	33%	6	75%
4	50%	11	33%	9	33%
8	42%	12	25%	13	25%
10	58%	Essay 5	50%	Essay 2	42%
Essay 1	50%			Essay 4	33%
Essay 3	42%				
Essay 6	33%				

Table 10:
Items of tendency towards mathematics scale

Dimensions	Items	Number of items
Nature of mathematics	1-2-3-4-5-6	6
Learning mathematics	7-8-9-10-11-12-13	7
Enjoying mathematics	14-15-16-17-18-19-20	7
Mathematics teacher	21-22-23-24-25-26	6
Total		26

Table 11:
Results of discriminant validity (Mann-Whitney U test) for the scale

Scale of tendency towards mathematics	*n* = 12	Mean Rank	Sum of Ranks	Z	p-value
Nature of mathematics	high scores	18.21	218.50	4.052	0.000
	low scores	6.79	81.50		
Learning mathematics	high scores	18.51	222.00	4.450	0.000
	low scores	6.50	78.00		
Enjoying mathematics	high scores	18.50	222.22	4.433	0.000
	low scores	6.50	78.00		
Mathematics teacher	high scores	15.92	191.00	2.413	0.007
	low scores	9.08	109.00		
Total	high scores	18.50	222.00	4.184	0.000
	low scores	6.50	78.00		

Table 12:
Pearson correlation coefficients for items the scale

Nature of mathematics		Learning mathematics		Enjoying mathematics		Mathematics teacher	
Item	Correlation coefficient	Item	Correlation coefficient	Item	Correlation coefficient	Item	Correlation coefficient
1	0.678**	7	0.599**	14	0.528**	21	0.398**
2	0.667**	8	0.684**	15	0.441**	22	0.469**
3	0.657**	9	0.418**	16	0.409**	23	0.490**
4	0.345*	10	0.648**	17	0.512**	24	0.649**
5	0.315*	11	0.631**	18	0.331*	25	0.606**
6	0.590**	12	0.685**	19	0.512**	26	0.468**
		13	0.349*	20	0.308*		

Note: * Correlation is significant at 0.05 level, and ** correlation is significant at 0.01 level.

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Table 12 shows that all scale items are statistically significantly correlated with the dimensions of the scale of tendency towards mathematics to which they belong at significance levels of 0.05 and 0.01. Correlation coefficients were also calculated between the score of each dimension of the mathematics inclination scale with other dimensions and the whole score of the scale (see Table 13).

Table 13:
Pearson correlation coefficients for dimension of the scale

Dimensions	Learning mathematics	Enjoying mathematics	Mathematics teacher	Whole
Nature of mathematics	0.556**	0.615**	0.315*	0.788**
Learning mathematics	-	0.670**	0.343*	0.878**
Enjoying mathematics	-	-	0.317*	0.796**
Mathematics teacher	-	-	-	0.515**

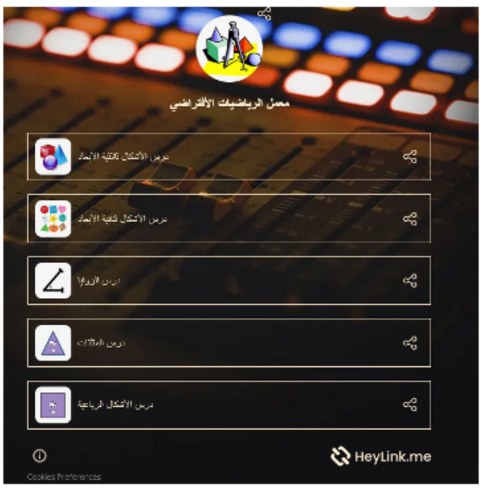
Note: * Correlation is significant at 0.05 level, and ** correlation is significant at 0.01 level.

Table 13 reveals that all dimensions of the scale are correlated with each other and with the whole score of the scale at a statistically significant level of 0.05 and 0.01. This confirms that the scale possesses a high degree of ability of its statements to discriminate.

Virtual Mathematics Lab

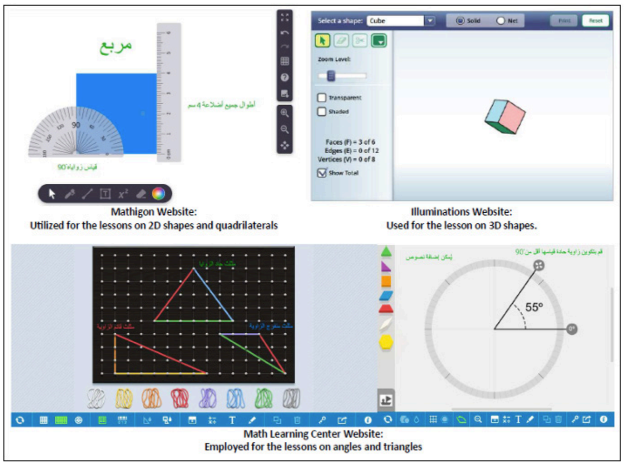
The virtual mathematics lab was developed to suit the selected instructional chapter "Identifying and Describing Geometric Shapes," which comprises five lessons: (Lesson on 3D shapes, Lesson on 2D shapes, Lesson on angles, Lesson on triangles, and Lesson on quadrilaterals). The Heylink software was utilized for designing the virtual lab due to its user-friendly interface and ease of organizing materials and tools in one place. Figure 2 displays the Home page of the virtual lab.

Figure 2:
Home Page of the Virtual Mathematics Lab



Three websites were chosen for inclusion in the virtual lab, and these sites are tailored to the age group of the participants. They are characterized by user-friendliness and their ability to achieve the chapter's objectives. Figure 3 illustrates the content and tools of the virtual mathematics lab and the website.

Figure 3:
Example of virtual lab contents and tools



The actual implementation of teaching the chapter "Identifying and Describing Geometric Shapes" was carried out by one of the researchers for both groups, as she is a mathematics teacher at the same school. The experimental group was taught using the virtual mathematics lab, while the control group was taught using traditional method. Teaching for both groups took 11 class sessions, with each session lasting 45 minutes.

Pre-Application of Study Instruments

Mathematics power test:

The mathematics power test was administered to both the experimental and control groups two weeks before commencing the teaching process of the "Identifying and Describing Geometric Shapes" chapter. This was done to ensure the equivalence of the two groups. Table 14 presents the results of t-test to identify differences between the experimental and control groups in the mathematics power test.

Table 14 indicates that all p-values are not statistically significant differences at a 0.05 level ($p>0.05$), suggesting no significant differences in the pre-application of the mathematical power test between the students in both groups. This confirms the equivalence of the research groups in the mathematical power test.

Scale of tendency towards mathematics:

The scale of tendency towards mathematics was distributed to both the experimental and control groups preliminarily to verify the equivalence of the two groups. Table 15 displays the results of the t-test to identify differences between the experimental and control groups in the scale of tendency towards mathematics.

Table 15 reveals that all p-values are not statistically significant differences at a 0.05 level ($p>0.05$), indicating no statistically significant differences in the pre-application of the scale of tendency towards mathematics between the students of both groups. This affirms the equivalence of the research groups on the scale of tendency towards mathematics.

Results and Discussion:

To answer the first question, which examines the effectiveness of the virtual lab in teaching mathematics in developing mathematical power in fourth-grade students in the Kingdom of Bahrain, the validity of the following hypothesis was tested: there is no statistically significant difference at a (0.05) level between the mean scores of students in the experimental group and the control group in the post-application of the mathematics power test. Table 16 indicates the results of the independent samples t-test to examine the differences between the two groups in the post-application of the mathematical power test.

Results from Table 16 indicate statistically significant differences at a (0.05) level between the scores of students in the experimental and control groups in the mathematics power test overall and its various dimensions, favoring students in the experimental group. Therefore, the null hypothesis is rejected, and the alternative hypothesis is accepted, which states that there is a statistically significant difference at a (0.05) level between the mean scores of students in the experimental group and the control group in the post-application of the mathematical power test.

Table 17 illustrates the effect size of the independent variable (using the virtual mathematics lab) by calculating eta squared (η^2) and the effect size *(d)* (Cohen, 1988).

Table 17 shows that the effect size of using the virtual lab in developing mathematical power overall and in the mathematical communication dimension was large (d = 0.81). However, the effect of using the virtual lab was moderate in the mathematical connection dimension (d = 0.61) and the mathematical reasoning dimension (d = 0.70) for fourth-grade students. This may be attributed to the fact that the virtual lab, in general, enhances students' practical skills through hands-on experiments and interactive environments, making students more engaged in the learning process. This, in turn, provides them with opportunities to understand the principles and concepts related to the scientific content accurately and deeply. Additionally, simulation programs in the virtual lab contributed to providing students in the experimental group with a clear set of events to actively participate in the simulation experience, offering them multiple options that suit their preferences and allowing them to deal with systems that may be difficult to handle under conditions that are hard to meet in regular classrooms. The virtual lab covered all course ideas through interactive practical experiments, enabling each student to expand their scientific imagination and develop their innovative ideas. It helped bridge the gap between abstract mathematical concepts and make them more tangible and understandable (Albyaty, 2006; Bajpai, 2012; Jung et al., 2006; Noufal, 2010; Stewart et al., 2006).

This result aligns with previous studies suggesting that mathematical power can be developed through the virtual lab (Abouassar, 2003; Almuqayed, 2017; Ismail, 2001). They also support the findings of O'Brien and Levy (2008), who noted that the virtual mathematics lab is characterized by an engaging interactive environment, providing easy ways to display algebraic, numeric, and equation applications. The virtual mathematics lab allows drawing curves, solids, and diagrams and presenting them in three dimensions, offering an attractive, colorful, and easy-to-use interface. It presents many options in the displayed tools, providing students and teachers with everything they need to understand and teach mathematical ideas, knowledge, skills, and theories and make them more realistic. These are important elements in enhancing processes related to mathematical communication, mathematical connection, and mathematical reasoning.

To answer the second question, which focuses on the effectiveness of the virtual lab in teaching mathematics in developing the tendency towards mathematics among fourth-grade students in the Kingdom of Bahrain, the validity of the following hypothesis was tested: there is no statistically significant difference at (0.05) level between the mean scores of students in the experimental group and the control group in the post-application of the scale of tendency towards mathematics. Table 18 indicates the results of the independent samples t-test to examine the differences between the two groups in the post-application of the scale of tendency towards mathematics.

Results from Table 18 indicate statistically significant differences at (0.05) level between the scores of students in the experimental and control groups in the scale of tendency towards mathematics overall and its various dimensions, favoring students in the experimental group. Therefore, the null hypothesis is rejected, and the alternative hypothesis is accepted, which states that there is a statistically significant

Table 14:
Result of pre-application of the mathematical power test

Dimensions	Group	*N*	*Mean*	*SD*	*df*	*t*	p-value
Mathematical communication	Experimental	33	6.42	1.92	62	0.568	0.572
	Control	31	6.71	2.10			
Mathematical connection	Experimental	33	3.91	1.04	62	0.471	0.639
	Control	31	4.03	1.05			
Mathematical reasoning	Experimental	33	4.24	1.32	62	0.461	0.646
	Control	31	4.39	1.117			
Whole test	Experimental	33	14.58	3.31	62	0.687	0.495
	Control	31	15.16	3.51			

Table 15:
Result of pre-application of the scale of tendency towards mathematics

Dimensions	Group	*N*	*Mean*	*SD*	*df*	*t*	p-value
Nature of mathematics	Experimental	33	14.85	2.69	62	0.446	0.657
	Control	31	15.16	2.91			
Learning mathematics	Experimental	33	17.06	2.69	62	0.620	0.538
	Control	31	17.48	2.77			
Enjoying mathematics	Experimental	33	17.12	2.76	62	0.835	0.407
	Control	31	17.71	2.88			
Mathematics teacher	Experimental	33	14.55	2.76	62	0.417	0.678
	Control	31	14.84	2.86			
Whole test	Experimental	33	63.58	10.17	62	0.617	0.539
	Control	31	65.19	10.82			

Table 16:
Results of t-test for mathematical power test

Dimensions	Group	N	Mean	SD	df	t	p-value
Mathematical communication	Experimental	33	10.33	0.98	62	2.92	0.0048**
	Control	31	9.32	1.76			
Mathematical connection	Experimental	33	5.58	0.71	62	2.39	0.0199*
	Control	31	5.03	1.08			
Mathematical reasoning	Experimental	33	7.30	1.02	62	2.76	0.0075**
	Control	31	6.45	1.43			
Whole test	Experimental	33	23.27	2.14	62	3.77	0.0003**
	Control	31	20.84	2.98			

Note: * p-value is significant at 0.05 level, and ** p-value is significant at 0.01 level.

Table 17:
Effect size of the virtual lab in the mathematical power test

Independent variable	Dimensions	*t*	*df*	η^2	*d*
virtual lab	mathematical communication	2.92	62	0.140	0.81*
	mathematical connection	2.39	62	0.085	0.61
	mathematical reasoning	2.76	62	0.109	0.70
	whole test	3.77	62	0.187	0.96*

Note: * is greater than (0.8).

Table 18:
Results of t-test for scale of tendency towards mathematics

Dimensions	Group	N	Mean	SD	df	t	p-value
Nature of mathematics	Experimental	33	17.24	1.28	62	2.64	0.0104*
	Control	31	16.06	2.21			
Learning mathematics	Experimental	33	20.00	1.22	62	3.60	0.0006**
	Control	31	18.26	2.48			
Enjoying mathematics	Experimental	33	20.12	1.24	62	3.82	0.0003**
	Control	31	18.26	2.49			
Mathematics teacher	Experimental	33	17.42	0.75	62	3.94	0.0002**
	Control	31	16.06	1.82			
Whole test	Experimental	33	74.79	3.81	62	3.79	0.0003**
	Control	31	68.65	8.45			

Note: * p-value is significant at 0.05 level, and ** p-value is significant at 0.01 level.

difference at (0.05) level between the mean scores of students in the experimental group (those who studied using the virtual lab) and the control group (those who studied using the traditional method) in the post-application of the scale of tendency towards mathematics.

Table 19 illustrates the effect size of the independent variable (using the virtual mathematics lab) by calculating eta squared (η^2) and the effect size *(d)* (Cohen, 1988).

Table 19:

Effect size of the virtual lab in the scale of tendency towards mathematics

Independent variable	Dimensions	*t*	*df*	η^2	*d*
Virtual lab	Nature of mathematics	2.64	62	0.101	0.70
	Learning mathematics	3.60	62	0.173	0.91*
	Enjoying mathematics	3.82	62	0.191	0.97*
	Mathematics teacher	3.94	62	0.200	1.00*
	Whole test	3.79	62	0.188	0.96*

Note: * is greater than (0.8).

Table 19 demonstrates that the effect size of using the virtual lab in developing the tendency towards mathematics overall (*d* = 0.96) and in its various dimensions is large, except for the tendency towards the nature of mathematics, which was moderate (*d* = 0.70), indicating the effectiveness of the virtual lab in developing the tendency towards mathematics among fourth-grade students. This may be attributed to the fact that using the virtual lab enhances students' engagement in mathematics activities, provides them with opportunities for imagination and expression of their thoughts, highlights the importance of mathematics in students' daily practical lives, simplifies mathematics, and presents it in an easy and exciting way to capture their attention. Additionally, the virtual lab stimulates students towards learning, generating positive attitudes towards mathematics, diversifying stimuli to help them acquire new inclinations, and integrating serious play into practical learning processes to engage and encourage them in the learning process (Albyaty, 2006; Bajpai, 2012; Jung et al., 2006; Noufal, 2010; Stewart et al., 2006).

This result aligns with studies that have addressed the development of the emotional aspect of learners when studying mathematics. Albasyouny et al. (2010) pointed out the effectiveness of the virtual lab in giving learners complete freedom to access information. Hassn (2019) affirmed the effectiveness of designing a virtual lab using different feedback patterns in developing aesthetic sensibilities in mathematics among elementary students. A study by Alhowaity and Albalawi (2019) indicated that the attitudes of mathematics teachers towards using augmented reality technology in teaching were positive and highly rated. Moreno-Guerrero et al.'s study (2020) found that e-learning has a positive impact on students' motivation and independence when learning mathematics.

This result is also in line with what Elnablsia (2018) mentioned, that the mathematics lab contributes to developing a tendency towards mathematics by removing boredom from students, making mathematics a fun, entertaining, and exciting subject to learn, and providing students with the necessary skills to use mathematics in their daily lives outside the school.

In answer to the third question, which queries the connection between mathematical power and the tendency towards mathematics among fourth-grade elementary students in the Kingdom of Bahrain, the validity of the following hypothesis was examined: There is no linear correlation between mathematical power and the tendency towards mathematics among fourth-grade students. To test this hypothesis, the Pearson correlation coefficient was computed between the scores of students in the experimental and control groups on the scale of tendency towards mathematics and their scores in the mathematical power test (see Table 20).

Table 20:

Correlation coefficients between the test scores and the scale scores

Variables	Groups	N	Correlation coefficients
correlation between the two variables	experimental	33	0.45*
	control	31	0.24

Note: * is significant at 0.05 level.

Table 20 reveals a positive linear correlation between the development of mathematical power and the tendency towards mathematics among students in the experimental group who were taught using the virtual lab. Conversely, no statistically significant correlation was found between these variables among students in the control group, who were taught using the traditional teaching method. This result for the experimental group students can be attributed to what Abuhelal (2012) pointed out regarding the correlation between tendency and learning. As a learner's tendency increases, so does their learning, coupled with an enhanced desire to comprehend the subject matter. All of this is reflected in the development of various dimensions of mathematical power among learners, encompassing mathematical communication (mathematical representation, mathematical listening, mathematical discussion, mathematical reading, and mathematical writing), mathematical connection (structural, contextual, and integrative connections), and mathematical reasoning (deduction, induction, prediction, and evaluation).

Table 20 showed that there is a statistically significant relationship (0.45) between the dependent variables (tendency towards mathematics - mathematical power) among students in the experimental group which can be attributed to the effectiveness of the independent variable (virtual lab). This variable provided a suitable educational environment tailored to the students' learning styles, reinforcing the teacher's role in motivating learners to study mathematics. It granted learners the opportunity to express their thoughts mathematically, engaged them in various activities, and emphasized the importance of the mathematical knowledge and skills they were acquiring by linking them to tangible aspects and real-life examples (Abuhelal, 2012). The virtual lab made mathematics an enjoyable, entertaining, and stimulating subject for learning, filling learners with positive expectations and enthusiasm for the math class. It also fostered an atmosphere of cooperation and respect among peers, as well as between teachers and students, equipping learners with the necessary skills to apply mathematics in daily life outside school. Furthermore, it encouraged collaboration, interaction, and competition among students, leading to increased motivation and enthusiasm for learning, which manifested in students' inclination towards mathematics (Elnablsia, 2018). On the contrary, the correlation coefficient in the control group (0.24) affirmed there is not a statistically significant relationship between the dependent variables (tendency towards mathematics - mathematical power). The reason behind this might be attributed to the use of the conventional teaching method, which renders mathematics a less engaging subject for learning, fails to motivate learners to participate in various activities during mathematics classes, and does not enhance their motivation while acquiring mathematical knowledge. Consequently, it does not contribute to the development of the various dimensions of mathematical power.

Conclusion:

This study aimed to assess the effectiveness of the virtual lab in teaching mathematics and its impact on the development of mathematical power and tendency towards mathematics among primary school students in the Kingdom of Bahrain. The results indicated statistically significant differences in the post-application scores for physical strength and the inclination towards mathematics between the experimental group (taught using the virtual mathematics lab) and the control group (taught using the traditional method). Additionally, a positive relationship was found between the development of mathematical power and the tendency towards mathematics among students in the experimental group who were taught using the virtual lab. This underscores the positive impact of the virtual lab on teaching and learning in primary education. The study recommends that the Ministry of Education in the Kingdom of Bahrain utilize the study results by establishing a virtual mathematics lab for primary education, recognizing its positive impact on enhancing effectiveness and engagement in various activities connecting mathematical concepts to students' daily lives. Curriculum designers are urged to develop and update mathematics curriculum to align with the integration of the virtual lab in both teaching and learning processes. Lastly, the current study recommends teacher preparation programs in Bahrain to design initiatives that help educators acquire the necessary skills to leverage technology, especially the virtual lab, in the teaching process for its positive impact on student learning.

Ethics Approval and Consent to Participate:

The research was approved by the Ethics Committee of the Imam Abdulrahman Bin Faisal University (IRB Number: IRB-2023-15-616). The research was conducted in accordance with the Declaration of Helsinki.

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