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Science Teachers' Use of Analogies: Findings from Classroom Practices

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Abstract: This paper is a quasi-experimental investigation into the effectiveness of using analogy in teaching new and unfamiliar physics concepts to students enrolled in a British curriculum school in the United Arab Emirates. The students (N = 34) were randomly assigned to one of two groups: the control group (N = 17) following the traditional teaching method, and the experimental group (N = 17) using the student-centered analogical method. The students relied on previous class knowledge to construct models, which in turn helped them explore new ideas and derive new knowledge. Pre-tests and post-tests were given to the two groups, where the post-test (test 6) results confirmed that the experimental group showed a more consistent outcome of high grades, no failure, and good homogeneity of results. On the other hand, the control group kept fluctuating around the same level in the all-study's tests (pre-test and repeated measures (tests 2,3,4 and 5). The effect size of the intervention was very large and practically important, at Cohen's d = 2.35. As a result, analogy-based pedagogies have demonstrated impact on students' learning performance and perceptions. Consequently, the result is capable of providing significant insights for educational policy and curriculum development.

Keywords: *Analogical thinking, analogy, students' attainment, teaching physics, transfer skills.*

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Introduction

From the day we start to learn about our surroundings, we look for things which are similar to what we normally see. Thus, making connections between new things and things we already know is considered an analogy. A child who wants a new folder might explain to his mother saying 'a folder that looks like the folder you keep your bills in'. We use analogy to make it easier to understand what something means, looks like, or how it works. Bean et al. (1985) described analogy as a mental tool we use in our brains to link separate ideas and hence become able to understand things around us. Glynn (1991) described the process of analogy as a ''process of identifying similarities between different concepts'' (p. 223).

Teaching by analogy may sometimes be confusing to students, especially when they come to study something new and cannot link it with something else, they already know. This confusion may lead them to misunderstand and misuse an analogy (Glynn et al., 1991). Teachers have strived very hard to come up with analogies to help their students understand science more easily (Glynn & Takahashi, 1998; Harrison & Treagust, 1993; Iding, 1997). How science works is sometimes hard to imagine, so if we create an analogy with something we already know, our knowledge of how something similar works becomes easier to understand.

Although previous studies have looked at students' usage of the symmetrical nature of the analogy relation (Wilbers & Duit, 2006, p. 47), there is a lack of research focused on students' use of analogies linked to their own previous knowledge. This in addition to the fact that, in the Arab world, there is a scarcity of research on using analogy in teaching physics. Duit et al. (2001) stated:

> A growing body of research shows that analogies may be powerful tools for guiding students from their pre-instructional conceptions towards science concepts. But it has also become apparent that analogies may deeply mislead students' learning processes. Conceptual change, to put it into other words, may be both supported and hampered by the same analogy (p. 283).

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Therefore, in this research, the researchers used what students have already learned as a build-up for new knowledge and as a gateway to pursue further learning, focusing on how this can be done. Thus, this quasi-experimental research aims to answer the following questions:

1. What is the impact of analogy-based instruction on student achievement in a secondary school physics classroom?
2. What are the perceptions of the analogy-based approach in teaching and learning physics?

Research Sub-Questions:

- Is there any significant difference between the pre-test mean scores of analogy-based instructions (experimental group) and traditional approach (control group) before intervention?
- Is there any significant difference between the post-test mean scores of analogy-based instructions (experimental group) and traditional approach (control group) after intervention?
- Does overall physics knowledge and skill increase, from the pre-test to the post-test, among the experimental group and the control group?

Framework

The focus of this research section is exploring the literature related to using and viewing analogy in sciences in general and in physics in particular, at different educational levels but especially in high school. According to Urone et al. (2020), Physics is a science that deals with observation and experiment. Education itself is the knowledge and skills that students acquire in school for application in everyday situations. Education has been described as "a dynamic process of building, organizing, and elaborating knowledge of the natural world" (Glynn & Duit, 1995, p. 3). The irregular case or what is referred to as "exception" is not the one we are after. In learning, students seek to relate new knowledge to previous knowledge they had learned before. According to well documented facts, students tend to memorize rather than understand the foundation of the concept. Research shows that students at university level learn the facts with a lack of in-depth understanding of the concepts. Consequently, many businesses across the region have "…called for educational reform because of an overemphasis on rote learning and memorization pedagogy common throughout all levels of education in the region" (Gillespie & Riddle, 2003), and Chickering and Ehrmann (1996) who assured the needs "… to eschew materials that are simply didactic, and search instead for those that are interactive, problem-orientated, relevant to real world issues and that evoke student motivation" (p.7).

The Role of Analogies and Metaphors in Learning Science

Recently, many studies focus on the effectiveness of analogy as instructional strategy in sciences in general and physics in particular. One of these studies, is a case study conducted by Surahman et al., (2020). The aim of the study is to investigate the ability of Senior High Schools students in constructing arguments that can generate physics analogy. They assumed that such created analogy can help students better understand the abstract and more complicated physics concepts. Data derived from the study confirmed that "Senior High School students that have been able to build a physics analogy will have a great opportunity to succeed in learning or will achieve a good achievement in learning" (p. 1).

Another new study conducted by Hesti (2021), aimed to highlight the effect of "analogy educational comics" – a variety of graphic novels that concentrate on a particular subject in a way that are enjoyable, fun and accessible – on clarifying student misconceptions. For this purpose, Simple Electrical Circuit Diagnostic Test (SECDT) was used to identify and detect students' misconceptions. According to the findings of the study, the analogy of educational comics can swap students' misconceptions with scientific truths and explanations presented in the comics.

Furthermore, Nikolaos and Ian (2020), in their study titled "Extending the Role of Analogies in the Teaching of Physics", claimed that analogy is capable of supporting physics teachers by providing them with a form of diagnostic assessments that can detect students' misconception and prior knowledge led to form such misconception. This information can be used as a basic source that can be efficiently used to augments the teaching process.

A recent study investigated analogy in teaching physics and secondary physics teachers' views and practices of analogy as a teaching-learning strategy in Bangladesh. Djudin and Grapragasem (2019), in response to the question related to the effect of the pictorial analogy models on students' achievement and retention of Direct Current lesson, the study confirmed that the use of pictorial analogy models can promote and augment student's achievement of Direct Current lesson and boosts their retention.

Another recent study conducted by (Fotou & Abrahams, 2020) suggested that analogies could be extended to provide physics teachers with a diagnostic form of assessment that can reveal the misconceptions their students may retain. Furthermore, prior knowledge upon which such misconceptions are based, as well as knowledge sources that can be productively used in the teaching process will also be revealed to teachers. For this purpose, this cross-age study was conducted. Students from five diverse age groups, were requested to generate predictions about a variety of new educational situations that they had not previously experienced. Students were also requested to clarify the motives that led them to make such predictions. Data regarding the most dominant participants' predictions in the two new situations and spontaneous generation of analogies per age group were collected, analyzed and tabulated.

Results revealed that analogies were spontaneously self-generated to help participants acquaint themselves with these two new experiences. Students were able to make and subsequently explain their prediction. Results confirm there were few correct predications in which students' spontaneous analogical reasoning supported the understanding of this present situation and guided them to the scientifically correct prediction. On the other hand, the wrong predictions were based on misconceptions that students retain.

According to Duit (1991), "Care is necessary when comparing what is said in literature about analogy and metaphor. Different authors usually have different, sometimes substantially different concepts in mind when employing these terms" (p. 2). Analogies and metaphors serve significant explanatory and heuristic functions in the development of science (Hesse, 1966; Leatherdale, 1974). Duit (1991) further indicated that "The role of analogies and metaphors in science instruction is usually discussed from the perspective of their significance in the learning process" (p. 21). If it is accepted that science instruction should not only teach scientific knowledge but also scientific meta knowledge, then the role of analogies and metaphors in science must be considered to be an essential aspect of science instruction.

Science Teachers' Use of Analogies: Observations from Classroom Practices

Treagust et al. (1992) scrutinized how science teachers employed analogies throughout their habitual teaching routines to facilitate students' comprehension of scientific concepts. A sum of 40 lessons instructed by seven different teachers were put under observation and analysis. In their study, the science teachers exploited few simple and enriched analogies as observed while teaching. The observations reflected that the teachers were well-informed about some of the beneficial and negative aspects of analogy, and that they used both analogies and examples regularly in their teaching, but they often did not differentiate between examples and analogies. The authors suggested that successful use of analogies in science-teaching classrooms requires a basis of a well-established teaching repertoire of analogies, with using definite content in definite contexts. They also suggested that science teachers should consider learners as being accountable for building their own knowledge rather than being inactive receivers of it.

Yerrick et al. (2003) sought to understand how preservice teachers interpreted curricular materials that promoted explicit use of analogies for understanding physical science and facilitated the practice of process skills in a guided inquiry environment. They explored the use of analogies in naturalistic settings. Given the uncertainty of personal and collective sense-making and the ordered, seemingly rigid structure of some curricula, they sought to examine the possibilities for how students might use analogies and process skills in collaborative problem-solving sessions. In doing so, they produced an existence proof to explicate some of the uses of analogies, knowing that students of this background will not completely embrace nor effectively use analogies in their normal discourse. Yerrick et al. (2003) found the teacher's role not a subject-matter authority or information disseminator, but rather an insider to the discipline with unique insights regarding how knowledge is created.

In addition, several current studies confirmed that physics subjects are accountable for organizing learning and structuring thought capable of boosting students' higher order of thinking and 21st-Century Skills and thus help enhance students learning gain (Aditomo & Klieme, 2020; Bao & Koenig, 2019; Burgin, 2020; Furtak & Penuel, 2019). Therefore, boosting students' higher order thinking skills should be a priority for all physics teachers/educators. The so-called "reviewed article" can be considered as a reminder that science/physics teachers play an important role in classrooms by guiding and scaffolding ways in which knowledge (particularly analogies) gets shaped, refuted, and promoted (Yanti et al., 2021). Exemplary curricula alone are no substitute for the teacher's role as the primary driver for rules of discourse in collaborative settings. This kind of classroom interaction stands in sharp relief to the kinds of talking science found in more conventionally managed classrooms. Traditionally, scientific discourse in a school setting is a teacher-directed monologue that masquerades as a student–teacher dialogue, in which students have little opportunity to discuss and pursue questions in ways that are meaningful to them (Lemke, 1990).

After reviewing the previous studies, the researchers did not find any national study that explores the effectiveness of using analogy technique of previous knowledge in physics, with new and unfamiliar physics concepts, in the United Arab Emirates. Thus, this is a major aim for conducting this research study. Consequently, this research attempts to fill this gap in related literature by identifying the impact of analogy strategy on physics achievement/attitude among high school students in local UAE schools.

Methodology

Research Design

This study adopted the quasi-experimental design as research method (Cohen et al., 2011) to help the researchers examine the students' achievement means scores before and after the experiment. A pre-test was applied to both research groups before the intervention. Then, students of the experimental group studied using analogy, whereas students of the control group studied using the traditional method. At the end of the intervention, a post-test was applied to both groups.

Participants

The study was carried out as an intervention experiment in a British curriculum school in Abu Dhabi, in the United Arab Emirates. The school serves about 1,400 students (K1 – 12) of both genders. There were two groups in this experiment, two grade 12 classes preparing for the Pearson Edexcel Advanced Level exam. A total of 34 students were selected to participate in this study and they were a mix of boys and girls. Each student in the two groups had an equal chance of being selected in any of the groups.

One of the classes formed the control group that consisted of 18 students and was taught the syllabus of physics subject using a Pearson-published textbook. The other class formed the experimental group that consisted of 16 students and was taught new concepts of physics using analogy of their previous knowledge acquired through their schooling. Upon completion of the course, all students would then sit for their external examination in A2 - Advanced Level physics.

Research Instruments

Several data collection instruments were utilized to explore the impact of analogy-based instruction on students' academic achievement in physics. These instruments consisted of a pre-test (1) and post-test (6), in addition to a repeated measures (tests 2,3,4 and 5) that were meant to involve multiple measures of the same variable taken over two or more time periods. These repeated measures aimed to confirm the obtained results that there were no significant differences in the participants' mean scores up until the post-test mean scores that showed a significant difference in participants' mean scores due to the effect of the analogy instructional intervention. Furthermore, a five-point-Likert scale questionnaire was conducted and utilized to explore experimental group's perception towards analogy instruction. The pre- and post-tests included all topics of the analogies used in the study, as well as the content material that was completed by all students in the previous years. The Pearson Edexcel exam A level was used for both pre- and post-tests. The Pearson Edexcel A level exams are designed for international students seeking to join the best universities around the world (https://qualifications.pearson.com).

In addition to the main pre-test (test 1) and post-test, the researcher conducted four assessment tests consisting of physics-based scientific problems given to students to solve using analogy. The aim of the tests is to confirm the physics learning gain and level of achievement of the participant of both groups (control and experimental). The Likert scale questionnaire was used to measure students' self-reported responses regarding teaching (13 items), attitudes towards learning (9 items), peer-to-peer relationships (4 items), class centralization (4 items), and learning outcome (6 items). The students were asked to answer the questionnaire after the experiment.

Face and content validity of the tests and Likert scale were confirmed. The tests and Likert scale questions were validated by experts in physics education, measurement and evaluation from local schools and Al Ain University.

For this mission, a total of 11 experienced science teachers from different local governmental and private schools, as well as 3 experienced faculty members from Al Ain University, rigorously reviewed the test and Likert scale questions' content. Their goal was to ensure that it meets the highest standards of quality and appropriateness. The tests and the Likert scale questionnaire were revised according to their feedback and submitted again to the same experts until they unanimously confirmed that the measurement instrument items were well-prepared, measuring what they claimed to measure as per stated objectives. This fact is considered as an approval and endorsement of the validity of the tests/questions.

Design of the Experiment

The research design is presented in Figure 1 below:

R	O_1	X	O_2	Experimental Group
R	O_3	⟶	O_4	Control Group

Figure 1: The Study's Pretest-Posttest Control Group Design

where R = Random Assignment; X = Experimental (Analogy Learning); O_1 and O_3 = Pretest; and O_2 and O_4 = Posttest.

The subject matters to be taught in class are what is required by "Pearson Edexcel International Advanced Level in Physics (YPH01)". The syllabus is both coherent and clear to the teacher and students. The content and assessment methods are stated and limited to what is required by the syllabus; however, the examination questions may include situations which may or may not be familiar to the students. The two groups had identical diagnostic pre-tests, that were held at the same time in the same exam hall, and the test environment and content were the same.

The control group was instructed in accordance to the syllabus, where everyday examples were used in the instructional methodology using the recommended and approved textbook. The control group class was a traditional teacher-centered one, where the teacher plays the main role explaining the lessons and giving notes. The experimental group was instructed the same content of the subject matter from the same textbook using analogy, yet the class was student-centered under the guidance of the teacher.

The experiment was to recall concepts learned in the previous year or years, knowing the main idea of how science works that when some action is taken, it causes something to happen. The class worked as one unit in recalling previous knowledge that was related to the new concepts they were learning. Due the short period of time available, a limited number of analogies were practiced. These analogies were used with the experimental group only.

The Analogy Technique Used

For more clarity, this section presents the "Spring-Capacitor" analogy as an example of the covered topics. In the following analogies, the students were encouraged to think of the way the "spring" operates and compare it to the way the "capacitor" works.

Table 1. The Spring-Capacitor Analogy

Spring (Previous Knowledge)	**Capacitor (New Concept)**
A force exerted on a spring produces an extension of the spring. And elastic potential energy storage	A p.d produced across a capacitor produces a charge on each plate. And electric energy storage
$F = kx$	$V = \frac{1}{C}Q$
For a strong spring (high k), a large force produces only a small extension. $f = kx$ is constant; when k increases, the value of x will decrease	For a small capacitor (low C, high 1/C) a large p.d produces only a small charge, $V = \frac{1}{C}Q$ if kept fixed, then if C decreases, then Q must also decrease

This example shows how a voltage produces charges on a capacitor plate in analogy with how a force causes an extension in a spring. The analogy was further carried out to explore the energy stored in the capacitor:

Table 2. Analogy of Exploring the Energy Stored in the Capacitor

Spring (Previous Knowledge)	**Capacitor (New Concept)**
The energy stored in a spring is $E_{mechanical} = \frac{1}{2}kx^2$	Then the energy stored in a capacitor will be as follows $E_{capacitor} = \frac{1}{2} \times$ (what is analogous with k, that is $\frac{1}{C}$) x(what is analogous with x, that is Q)^2 hence, by analogy, the energy stored in a capacitor takes the form, $E_{capacitor} = \frac{1}{2} \times \frac{1}{C} Q^2$ And it works.

Combination of Capacitors

Given three springs constants $k_1, k_2, and\ k_3$ of the same length and hanging in parallel side by side, and loaded with one load F/(N), calculate the equivalent spring constant of the three springs. You are also given three capacitors $C_1, C_2, and\ C_3$ connected in series.

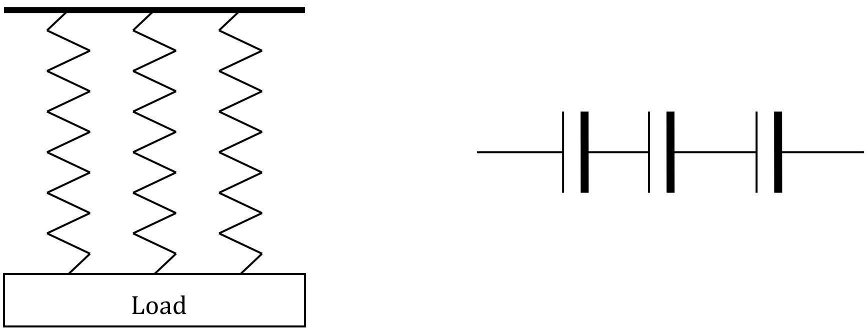

Figure 1. Capacitors in Series and in Parallel

Table 3. Capacitor-Spring Analogy

Springs	**Capacitors**
* Each spring will have the same extension. * The load is divided between the three springs, $F_1, F_2, and\ F_3$ $F_{total} = (F_1 + F, + F_3) = (k_1 + k_2, +k_3)x$ Then $k_{total} = k_1 + k_2 + k_3$	* Each capacitor will store the same amount of charge. * The potential is divided between the three capacitors, Capacitors, $V_1, V_2, and\ V_3$. *$V_{total} = V_1 + V_2 + V_3 = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right) Q$ * Hence, and by analogy, $\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$, and it works.

A charged capacitor discharged through a resistance is similar to the decay curve of a radioactive substance

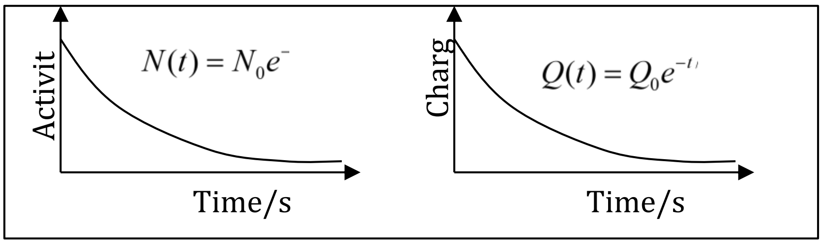

Figure 2. Comparing Charged Capacitor with Radioactive Substance

Hence, by analogy in physics, the charge at any time and also the current in the resistor may be presented as follows:

$$Q(t) = Q_0 e^{\frac{-t}{RC}} \quad \text{in analogy with} \quad N(t) = N_0 e^{-\lambda t}$$

$$I(t) = I_0 e^{\frac{-t}{RC}} \qquad A(t) = A_0 e^{-\lambda t}$$

λ is the decay time constant of the radioactive substance and hence has a unit of s^{-1}, and so does the capacitive time constant RC have a unit s.

Table 4. Comparison Between Radioactive Decay and Capacitor Discharge

Radioactive decay	**Discharge of a capacitor**
$* A = \lambda N$	$* I = \frac{1}{RC} Q$ The current I is analogous with the activity, and the charge at any time is analogous with the number of radioactive atoms present in the sample.
$* \lambda t_{1/2} = ln2 \Rightarrow t_{1/2} = \frac{ln2}{\lambda}$	$* \frac{1}{RC} t_{1/2} = ln2 \Rightarrow t_{1/2} = RCln2$ Here again, by analogy, it works

This was an example of the analogies used and the outcomes. Other analogies were also used in this experiment, such as the quadratic equation with projectile motion and Cyclotron analogy with Newton's laws of motion. Because of space constraints in the article, the presentation of such analogies has been left out of the article.

Findings

Mean and standard deviation were used to answer the research questions. The data collected form the tests were analyzed with Online Box Plot Generator – Alcula, online Calculators. The generated results of the pre-test, post-test, and experiment assessment tests are displayed in the sections below and used to answer the research questions.

Pre-test (Test 1)

The following data generated from analysis of the diagnostic pre-tests of all participants (Test 1) confirms that the two groups (the experimental and the controlled group) were at the same level at the start point of the study and before the interventions. This generated fact was confirmed by the repeated measures (tests 2, 3, 4 and 5) that are meant to involve multiple measures of the same variable taken over two or more time periods. These repeated measures attested that there were no significant differences in the participants' mean scores before the post-test as shown in tables 5 and 6. Consequently, both control and experimental groups scored almost the same results in the pre-test as shown in Tables 5 and 6. The mean and standard deviation for the control group were 9.72 and 2.68 respectively, while for the experimental group, they were 8.98 and 3.85 respectively.

The second sub-question needed to be answered in order to be able to address the main research question and confirm whether or not analogy instruction intervention impacted participants' achievements.

For this purpose, in addition to the pre-test and according to the repeated measures, the students had four different assessment tests during the intervention experiment. The control group maintained the same level throughout the research period, but the experimental group showed improvement in each successive test. Following are the results of each of these four assessment tests.

Analysis of Test 2

The experimental group used analogy of the quadratic equation in solving the projectile problem. The first test showed a significant difference between the two groups, where some failed the test in the control group, while no one failed it in the experimental group as shown in Tables 5 and 6. The mean and standard deviation for the control group were 14.61 and 4.14 respectively, while for the experimental group, they were 22.19 and 2.94 respectively.

Analysis of Test 3

The experimental group used the analogy of the springs to solve the capacitor circuits. As seen in Table 5 and 6, the control group did well, but the experimental group did exceptionally well. The mean and standard deviation for the control group were 6.17 and 1.77 respectively, while for the experimental group, they were 9.19 and 0.88 respectively.

Analysis of Test 4

The experimental group used the analogy of nuclear decay to solve questions about the discharge of the capacitor. The control group's results remained the same as before, while the experimental group showed a smaller interquartile range with very high average as seem in Tables 5 and 6. The class was moving towards being a homogeneous class; meanwhile, the control group was still heterogeneous. The mean and standard deviation for the control group were 6.61 and 2.17 respectively, while for the experimental group, they were 10.87 and 0.98 respectively.

Analysis of Test 5

The two groups had to devise a method of critical thinking using an everyday situation to explain a modern physics problem. In the critical thinking problem, the control group did terribly. Their critical thinking skills were not enough to understand and tackle a real-life situation, so most of the class failed. This brings fear that the class will face trouble in the external exam. On the other hand, the experimental group surprised the researcher as they finished the test in a short period of time and the interquartile range improved as seen from the results in Tables 5 and 6. This means, we had a homogeneous class with a high attainment level. The mean and standard deviation for the control group were 3.67 and 1.67 respectively, while for the experimental group, they were 9.62 and 0.48 respectively.

Analysis of Post-test (Test 6)

This test was used to examine knowledge of the of the previous knowledge in a similar manner to the pre-test and it revealed an added and unintended outcome. Though there was no intention to work on strengthening previous knowledge, and only a desire to use previous knowledge, the students in the experimental group showed mastery of the previous knowledge, meanwhile, the control group remained at the starting level as seen in Tables 5 and 6. The mean and standard deviation for the control group were 9.44 and 2.83 respectively, while for the experimental group, they were 19.87 and 0.48 respectively.

Table 5. Analysis of Pretest and Posttest.

Tests	Control Group Mean	Experimental Group Mean	Control Group Std. Deviation	Experimental Group Std. Deviation	Results		
					Pre-test	**Post-test**	**Std. Deviation**
Per-test	9.72	8.98	2.68	3.85	There is no statistical differences between experimental and control groups in terms of their mean score (success).	There is a statistical differences between experimental and control groups in terms of their mean score (success).	{Cohen's d = (19.87 - 9.44) / 2.029692 = 5.13871.d of 2.35} A Cohen's d that is bigger than 1 indicates a huge impact of the analogy intervention.
Post-test	9.44	19.87	2.83	0.48			

Table 6. Summary of Study's Tests Results

Study's Tests	Control Group Mean	Experimental Group Mean	Control Group Std. Deviation	Experimental Group Std. Deviation	Results	
					There is Significant Difference	**There is no Significant Difference**
Per-test/Test 1	9.72	8.98	2.68	3.85		X
Test 2	14.61	22.19	4.14	2.94	X	
Test 3	6.17	9.19	1.77	0.88	X	
Test 4	6.61	10.87	2.17	0.89	X	
Test 5	3.67	9.62	1.67	0.48	X	
Posttest-/Test 6	9.44	19.87	2.83	0.48	X	

Effect of the Analogy on Physics Learning

As indicated by our analysis of the boxplots, the controlled group started with a mean of (M = 9.72) on the first test and ended with a mean of (M = 9.44) on the sixth test. which means that the two scores were the same. While the experimental group started with a score of (M= 8.98) in the first test and jumped to a score of (M = 19.87) in the sixth test. This is evidence that the experimental group recorded improvements in physics scores as a result of their respective intervention conditions. Their improvements are summarized in Tables 5 and 6. From the descriptive statistics presented in this table, we can see that the experimental group's physics achievements increased by more than two twofold, that is from 8.98-point average to a 19.87-point average, while the control group stayed the same. Thus, the physics performance of the experimental group (M = 19.86, SD = 2.83) was superior to the control group (M = 8.98, SD = 0.48) by almost 11 points.

Practical Importance and Magnitude of the Analog Intervention Effect

A subsequent effect size analysis of the groups' difference in gain scores produced a Cohen's d = (19.87 - 9.44) / 2.029692 = 5.13871.d of 2.35. This fact suggests a huge impact of the analogy intervention. A Cohen's d that is bigger than 1 means that the difference between the two means is larger than one standard deviation. For the present study, the analogy intervention produced a mean difference of more than 2.35 standard deviation between the experimental and control groups.

Consequently, by comparing the control and experimental groups, one can notice that the two groups started at the same level. The control group fluctuated around the same level but the experimental group kept on improving throughout all the tests.

Pearson Edexcel Post-Test

At the end of the experiment, a post-test was conducted, as 18 students from the control group and 15 students from the experimental group were tested by Pearson Edexcel exam A level. The control group achieved almost the same results as in the diagnostic pre-test, on the other hand the surprising outcome was that of the experimental group, who mastered the test. Out of 15 students from the experimental group, 11 scored 100+ out of 120. The results are summarized in the Table 6 below. The mean and standard deviation for the control group were 59.44 and 23.48 respectively, while for the experimental group, they were 106.6 and 11.72 respectively.

Table 6. Pearson Edexcel Exam Results

Control group (N=18)		Experimental group (N=15)	
Student number	**Mark/ 120**	**Student number**	**Mark/ 120**
0109	77	0108	113
0115	25	0111	92
0122	52	0117	120
0135	94	0123	120
0137	82	0134	106
0144	66	008	117
0013	63	0021	102
0012	42	0025	120
0003	31	0035	93
0028	36	0041	96
0040	48	0060	120
0042	16	0126	110
0057	87	0124	82
0058	90	0153	108
0064	87	0154	100
0068	72		
0104	42		
0117	60		

Once more, by comparing the control and experimental groups, the post-test Pearson EdExcel exam results indicate positive performance results showing mastery of the subject by the experimental group. Therefore, and based on these statistics, the study's hypothesis (i.e., the experimental group will produce a significantly higher physics' achievement than the control group as a result of the analogy intervention) was empirically supported.

Therefore, the data generated from different tests assured that there is a significant difference between the experimental group and the controlled group mean score for the favor of the experimental group.

The overall result of the tests' analysis generated the answer for the following sub-question:

- Does overall physics knowledge and skill increase, from the pre-test to the post-test, among the experimental group and the control group?

The external exam allowed the researchers to further compare student attainments and showed that although there is a great difference between the two groups, the experimental group results are persistent within acceptable variation, while the control group's results were varied with a great deal of percentage difference.

In the next section, the Likert scale data and analysis will be explored and interpreted to answer the following questions.

- What are the perceptions of the analogy-based approach in teaching and learning physics?

For this aim, the results of the Likert scale questionnaire are displayed in the 7 tables below. They describe respectively students' self-reported responses regarding teaching, attitudes towards learning, peer-to-peer relationships, class centralization, and learning outcome.

Results of the Questionnaire

As seen in Table 7, four statements scored more than 90% approval by students, while four other statements scored higher than 80%, which indicates that this teaching method succeeded across these areas. In addition, four other statements scored above 70%, which is acceptable. However, helping the student to become creative scored the least at 29.1%, which reveals that more work should be done in this area.

Table 7. Students' Responses Regarding Teaching

Statement	5 Strongly agree	4 Agree	3 Slightly agree	2 Slightly disagree	1 Strongly disagree	% Overall rating
I feel very comfortable with the material after this teaching method	14	2				95.8%
I felt this term's classroom helped me understand the material better	12	4				91.6%
The thought analytical experiments we learned yielded visible results	10	4	2			83.3%
Teaching by analogy helped me apply knowledge to a real-world scenario	9	2	5			75%
I have felt involved in the teaching-learning process	12	4				91.6%
I felt confident about my understanding	10	3	3			81.2%
I learned new methods of critical thinking	9	5	2			81.2%
Learning physics by analogy helped me manage other subjects	7	4	5			83.3%
Learning by analogy helped me recall previous knowledge	15	1				95.8%
Learning by analogy helped me feel comfortable around hard questions	10	1	5			77.1%
Learning by analogy strengthened my analytical skills	8	3	5			72.9%
Learning physics by analogy helped me become creative		5	4	7		29.1%
Learning physics by analogy helped me become a self-learner	7	6	2	1		72.9%

As seen in Table 8, majority of the statements scored 100% demonstrating significant success. Meanwhile, discovering one's abilities scored 75%, which was satisfactory, and deciding on one's future career scored 27%, which can be attributed to a lack of career advice in school.

Table 8. Students' Attitudes Towards Learning

Statement	5 Strongly agree	4 Agree	3 Slightly agree	2 Slightly disagree	1 Strongly disagree	% Overall rating
I started loving physics	16					100%
I established a passion for learning	16					100%
I feel more comfortable in the classroom	16					100%
I feel happy with my accomplishments	16					100%
I started admiring and appreciating learning	16					100%
Learning had become a joy	16					100%
I now love school more than ever	16					100%
I am now more decided on my future career	5		2	5	4	27%
I have discovered my abilities	6	4	6			75%

As seen in Table 9, the peer-to-peer relation was a total success, with all four statements scoring 100%.

Table 9. Peer-to-peer Relationship Results

Statement	5 Strongly agree	4 Agree	3 Slightly agree	2 Slightly disagree	1 Strongly disagree	% Overall rating
I have established better relations with my peers	16					100%
I now value teamwork with my peers	16					100%
I started caring for my peers' accomplishments	16					100%
I feel the class is like a caring family	16					100%

As seen in Table 10, majority of students agreed that the class had become student-centered and this is considered a positive change. As for note-taking, the result show that some students are still dependent on the teacher's explanations or instructions to take notes. The students generally indicated feeling more in control of the class, despite some reliance on the teacher when it came to taking notes.

Table 10. Class-centralization Results

Statement	5 Strongly agree	4 Agree	3 Slightly agree	2 Slightly disagree	1 Strongly disagree	% Overall rating
The class is no longer a teacher-centered	12	3	1			89.6%
The class became student-centered	12	3	1			89.6%
Learning became deductive based on teacher's leading questions	16					100%
I am no more dependent on taking notes, I make my own notes	9	2	2	2	1	66.7%

As seen in Table 11, all the students are confident that they have learned physics in a new way, and they are proud of their grades. They have become more self-dependent as far as assignments and writing exams are concerned. However, the results show that they still feel worried about external exams and challenging questions.

Table 11. Learning Outcome Results

Statement	5 Strongly agree	4 Agree	3 Slightly agree	2 Slightly disagree	1 Strongly disagree	% Overall rating
I have learned physics in a new interesting way	16					100%
My grades became above expectations	16					100%
I am no more afraid of challenging questions	8	2	2	4		62.5%
I am more comfortable writing exams	10	3	2	1		79.2%
I no longer need help with my assignments	12	3	1			89.6%
I am more confident about my external exams and looking forward to them	6	3	3	4		56.3%

Discussion

Physics incorporates the science of matter, motion and energy. A more advanced and complex area of physics is usually taught at high school levels. That's why teachers usually face difficulties in simplifying the main concept. Teachers and physics educators are constantly seeking methods and means that can help them teach in a more meaningful way. Therefore, it is an opportunity to rethink how physics education should work and improve.

Based on the above facts, in addition to the fact that the more you know, the easier it will be for you to learn new things, this study was conducted. This research is carried out in the form of a quasi-experimental study that investigates the efficiency of using analogy in teaching physics, which involves applying existing knowledge in unfamiliar situations. This study contributes to the broad effort by the physics education research community to enhance instruction through a better understanding of student learning. For the purpose of inspecting the effectiveness of analogy on learning gains of physics, the researchers hypothesized the following:

H_1: The experimental group will produce a significantly higher physics achievement than the control group due to the analogy intervention.

As hypothesized, the analogical instruction did lead to better conceptual understanding of physics concepts. As presented in tables 5 and 6, the results of the pre-test revealed that the two groups started at the same level, scoring almost the same at the pre-test; however, the control group fluctuated around the same level while the experimental group kept on improving throughout the study and showed positive performance improvement indicating mastery of physics.

Consequently, the results of comparing the mean scores and std. deviation of the two groups (control and experimental) and the Pearson Edexcel Post-Test, all attested to the fact that analogy-based instruction was able to produce substantially large gains in student learning as a result of the approach. Additionally, the effect size of the gain was also very large, i.e., more than 1 standard deviation, and practically important, suggesting that the analogy instruction was really effective in improving students' learning of and performance in Physics. Therefore, the hypothesis was strongly supported.

The study data aligned with most previous studies (e.g., Aditomo & Klieme, 2020; Bao & Koenig, 2019; Brown, 1993; Burgin, 2020; Chiu & Lin, 2005; Furtak & Penuel, 2019; Glynn, 1991; Harrison & Treagust, 1993; Thiele & Treagust, 1994, 1995 etc.) on the positive impact of analogy-based learning on students' learning achievements—this was clearly reflected in their considerable gain scores. The effect size of the gain was also very large, i.e., more than 1 standard deviation, and practically important, suggesting that the analogy instruction was really effective in improving students' learning of and performance in physics. The effect size produced in the study approximated the practical importance of analogy learning demonstrated by (Hussey & De Houwer, 2018). On the other hand, several studies confirmed that analogy did not work well for all students and analogy may be a possible logical trap as well as an invaluable intellectual tool (Brown & Salter, 2010; Nagel, 1971). Furthermore, the large practical importance of the present study's intervention could have been contributed by the cognitive strategy proven to augment students' learning and understanding of content.

Conclusion

Therefore, assuming that students retain knowledge, they acquired in the past without continued engagement with it is wrong. Instead, this treasure in the brains of students is like a jewel that needs to be polished from time to time. Learning is a step-by-step process to build a skyscraper of knowledge. When we build something new, we must be aware of what prior blocks we are building on. When students find it hard to understand something new, it is because they did not understand or could not recall the pre-requisite knowledge from the past. The idea of a heterogeneous class is no longer a fact in our minds. We believe that each student is capable and can be amongst other high-potential students.

The experimental group ended up being 100% homogeneous. The students in the control group were the first to notice the difference in the achievement level compared to their peers in the experimental group. They felt that they were falling behind, especially when comparing their results on the same exam to their peers' results in the experimental group. They repeatedly asked to join the experimental group. For the sake of the integrity of the research, such requests could not be granted. We promised members of the control group to repeat the procedure with them as soon as the research period was over, and they completed the external examination. This study is considered to be one of very few empirical studies in UAE that investigates the effect of analogy-based instruction in teaching physics for high school students who are enrolled in a British curriculum school in Abu Dhabi in the United Arab Emirates. In addition to the fact that as an Arab developing country, the findings of this study have implications not only for UAE but for other Arab countries that are keen to integrate technology in their classroom.

Recommendations

Based on the outcome of this study, students' exposure to analogy-based instructional methods can lead to a noticeable and significant increase in academic achievement. This study contributes to better acquaintance with teaching approaches to physics in high school, and how they are associated with students' conceptual learning. Data derived from the study has confirmed that when analogical instruction is used in a consistent way, students' understandings of physics concepts will increase while misconceptions will definitely decrease.

Thus, the study also attested that analogy-based instruction is more enhancing to the teaching/ learning process than traditional/conventional instruction. Consequently, the study encourages science teachers to use analogical instruction more often in their classroom to optimize clarity to promote student learning. The result of the study also encourages the educational authorities in UAE to train teachers to be able to adopt and systematically use analogy in teaching and learning science in general and physics in particular. UAE and other educational authorities are inspired to provide guidelines for teachers through in-service and professional development programs. Furthermore, physics textbook writers can track this study to include appropriate analogies for abstract and complicated concepts.

Additionally, the researchers proposed several recommendations for physics teachers to help them improve their teaching/learning practices:

1- Triggering various knowledge of students is one of the most important factors to learning in physics education as suggested by Ausubel (1968).

2- Deeper conceptual understanding of abstract concepts in physics can only be sufficiently done using analogy as confirmed by Harrison and Treagust (1993).

3- Physics teachers should be encouraged to adopt the analogy-enhanced instruction to simplify basic physics.

4- Teachers should attend training courses on the use of the analogy enhanced instructional strategy in order to help their adoption.

On the other hand, since the research population was from grade 12 students only, who are mature enough with a vast amount of previous knowledge and therefore expected to respond effectively, a future study may focus on students from lower grades to allow for more generalization of the results.

Limitations

This intervention experiment took place in a relatively short period. The intended syllabus was not completed during this study. There were more analogies to explore but some were delayed until later on, to prepare the students for sitting for their external examinations.

Authorship Contribution Statement

Shana: Conceptualization, editing/reviewing & supervision. El Shareef: Design, data collection, analysis & writing.

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