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Integrating Energy-Based Approaches into Chemistry Teaching: An Experimental Study on Curriculum Effectiveness in Algerian Middle Education

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Keywords Curriculum innovation; Energy-based teaching approach; Chemistry education; Student achievement; Middle school education; Algeria.

Abstract
This study examines the effectiveness of a chemistry teaching programme structured around the concept of energy as a unifying approach in Algerian middle education. Energy, as a central scientific concept, provides a cross-cutting framework that connects chemical processes, physical phenomena, and real-life applications. Despite its centrality, the Algerian middle school chemistry curriculum has traditionally introduced energy in a fragmented manner, limiting students' capacity to establish meaningful conceptual connections across topics.
The primary aim of this research was to design, implement, and evaluate a curriculum that integrates energy as a guiding principle for teaching chemistry to first- and second-year middle school students. The study employed an experimental design involving 150 students (male and female) drawn from different schools in Algiers. The experimental group received instruction using the energy-based curriculum, supported by specially designed teaching cards, a teacher's guide, and tailored achievement tests. The control group continued with the conventional curriculum.
Quantitative data were analysed using statistical tests at a 0.01 significance level. Results indicated that the experimental group outperformed the control group in achievement tests, demonstrating that the energy-based approach had a significant positive effect on learning outcomes. Furthermore, a strong positive correlation was found between students' achievement and their exposure to the new curriculum. These findings underscore the pedagogical value of employing energy as an integrative concept in chemistry teaching.
The study concludes by recommending the gradual inclusion of energy-based units into national chemistry curricula, extending the pilot programme to diverse geographical and socio-cultural contexts in Algeria, and providing systematic teacher training. Such initiatives could strengthen students' conceptual understanding, scientific literacy, and readiness for higher levels of scientific study.

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Introduction:
The teaching of sciences aims at understanding three parts: knowledge, skills, and attitudes. The main objective of science teaching is to provide students with experiences that help them become scientifically literate, as the modern

view of science learning includes mathematics, natural sciences, and technology in addition to social sciences. This objective involves placing students in the first rank among the world's nations in achievement in science and mathematics. In modern sciences, students are prepared to participate in civic life, to be productive workers and lifelong learners, as this vision adopts the idea that students will be loyal citizens striving to establish a strong democracy that supports the nation's economy and maintains an advanced position in science and technology. The modern vision of science learning directs us to the philosophy of "less is more," meaning the trend is towards teaching fewer topics while achieving more hands-on work and deeper learning (Al-Huwaidi, 2010, p. 43).

Chemistry is one of the subjects that students should study during their science education, as it relies on the experimental research method, enabling students to acquire skills specific to this method. Chemistry is connected to their daily lives, helping them solve everyday problems, providing them with cognitive skills to interpret some surrounding phenomena, manual skills, and fostering positive attitudes towards science and scientists.

The content of science for the preparatory stage, as approved by the National Academy of Sciences (NAS) in the United States, is classified into seven main topics (known as the national standards for middle school science content), namely: standards of developing and understanding scientific inquiry, standards of physical and chemical sciences, standards of life and environmental sciences, standards of earth and space sciences, standards of science and technology, standards of science from a personal and social perspective, and standards of the history and nature of science. Students at this stage study three main topics in physics and chemistry:

First topic: Properties of matter and the changes that occur to these properties, which include the following standards: density, boiling point, solubility, separation of mixture components. Materials react chemically in various ways to form compounds with completely different properties. Elements react together in multiple ways to form compounds that explain the existence of living and non-living materials encountered.

Second topic: Motions and the forces causing them.

Third topic: Transfer of energy, which includes the following standards: energy is related to heat, light, motion, mechanics, sound, nucleus, and the nature of chemical matter. Energy can be transformed in various ways. Energy is transferred in multiple ways. Nuclear or chemical energy can be transferred inside or outside a given system (Al-Najdi & others, 2005, pp. 61–62).

Chemistry is taught in middle education in Algeria as one of the fields of physical sciences and technology, called: The Field of Matter and its Transformations. The focus is on teaching the microscopic structure of matter and explaining all physical and chemical changes using models, i.e., the chosen teaching approach is: the structure of matter.

It has been observed that students at this age do not comprehend these models as they are not connected to their lives. It would have been more appropriate first to acquaint students with the surrounding chemical materials, describe them, know their properties, the reactions of these materials with one another, and how to benefit from these reactions if possible, then move to microscopic interpretation. We agree with Henry (1976, p. 339) that students need from the start to understand: (a) what they see happening in test tubes, beakers, and flasks; (b) the energy changes that accompany matter changes; (c) the molecular or ionic structure of the materials involved in (a) and (b), and how these help us understand (a) and (b).

For this reason, we proposed another approach to teaching chemistry in middle education: energy. Energy is considered one of the unifying ideas in science teaching. Among the key concepts that should be taught in science in middle school, Pierre (2010, p. 18) mentioned the following: energy transforms in some changes and phenomena, but the total amount of energy remains constant in the universe. This emphasizes the need to link all physical and chemical changes with energy changes, whether absorption or release of energy. According to Henry (1976, pp. 340–341), to introduce energy concepts in education, they should be introduced gradually, considering the student's age. He proposed introducing them in four stages:

First stage: Developing knowledge of thermal changes and stressing that physical change is accompanied by thermal change.

Second stage: Some simple expansion of meanings of heat capacity and latent heat of changes that do not result in new materials, then presenting energy according to kinetic theory. Afterwards, considering physical changes as giving a simplified picture of the meanings of bond formation and breaking.

Third stage: Students should as early as possible get used to interpreting the tendency of reactions to occur in the direction of (a) gas release, (b) precipitate formation, (c) production of a weak electrolyte. These lead to discussions on equilibrium in cases of competing effects. At this stage, the difference between ΔH and ΔG should be clarified.

Fourth stage: More difficult, represented in the importance of energy transformation. It is desirable to provide a simple explanation of entropy changes in the system and universe. Reactions where ΔH is greater than ΔG, nearly equal, or smaller should be discussed. The idea of entropy should be introduced using terms of disorder and randomness as a function of the number of particles. This stage requires careful research, and I believe it is very important that more advanced students receive some information about the role and significance of entropy. At the middle school stage, we will limit ourselves to the first and second stages, where students should know that physical or chemical changes are accompanied by changes in temperature, i.e., changes in energy. Then they should know that materials decompose, their bonds break, and reorganize in another form to create new materials.

Several studies have addressed the concept of energy in different educational subjects. Among them is the study of Yassin Mohammed (2015), which shares with our research the proposal of a chemistry program according to energy concepts. This study aimed to build a teaching–learning program according to renewable energy and nanotechnology concepts and to examine its effect on technological literacy and ethical scientific awareness among third-year students in the Department of Chemistry. To verify this goal, the following null hypotheses were set: (1) There is no statistically significant difference at the 0.05 level between the mean scores of students in the experimental group who study nanotechnology and renewable energy using the teaching–learning program and the mean scores of students in the control group who study the same subject using the traditional method in technological literacy. (2) There is no statistically significant difference at the 0.05 level between the mean scores of students who study nanotechnology and renewable energy according to the teaching–learning program and the mean scores of students in the control group who study the same subject using the traditional method in ethical scientific awareness. The experiment was applied in the first semester of the academic year (2014–2015) on a purposive sample of third-year students in the Chemistry Department, College of Education for Pure Sciences – Ibn al-Haytham. The research sample consisted of 47 students, with 24 in the experimental group and 23 in the control group chosen randomly. The quasi-experimental design with a post-test for two equivalent groups was used. The teaching–learning program was built according to its approved stages, and the content was prepared from renewable energy and nanotechnology concepts. Two research tools were prepared: the technological literacy scale and the ethical scientific awareness scale. The technological literacy scale consisted of 36 items distributed across four domains: cognitive, skill, emotional, and socio-ethical. Its validity and reliability were verified. Statistical tools used included the t-test, factor analysis, Pearson correlation coefficient, effect size equation, and means. The results were as follows: (1) A statistically significant difference between the experimental and control groups in technological literacy in favor of the experimental group, with an effect size of 1.4. (2) A statistically significant difference between the experimental and control groups in ethical scientific awareness in favor of the experimental group, with an effect size of 1.2. In light of these results, the researcher recommended adopting the teaching–learning program based on renewable energy and nanotechnology concepts as part of the general curriculum of faculties of science education, as well as paying attention to modern scientific concepts to achieve better educational outcomes. She also suggested conducting further studies as a continuation of this research.

As for the study of Ali Siyam (2008), it aimed to identify the effect of a program calculated with individualized learning, training, and practice in teaching the unit of energy on scientific skills among seventh-grade students in physics. To answer the research questions and test its hypotheses, the researcher selected a purposive sample of seventh-grade students at Rafah Boys' Preparatory School for Refugees, consisting of three sections with a total of 90 students divided into three groups: the first experimental group (30 students), the second experimental group (30 students), and the control group (30 students). The study relied on two tools for data collection: an achievement test of cognitive scientific skills in the unit of energy composed of 40 multiple-choice items, and an observation card of performance scientific skills in the unit of energy composed of 14 items. The study concluded the following: there were statistically significant differences at the 0.05 level in cognitive scientific skills attributed to the teaching method, in favor of the first experimental group over the control group, showing the effectiveness of the program based on individualized learning, training, and practice in developing cognitive scientific skills in the energy unit among seventh-grade students. There were statistically significant differences at the 0.05 level in performance scientific skills attributed to the teaching method, in favor of the first experimental group over the control group, and there were statistically significant differences at the 0.05 level in favor of the first experimental group over the control group, showing the effectiveness of the program based on individualized learning, training, and practice in developing performance scientific skills in the energy unit among seventh-grade students.

Problem of the Study:

The teaching of chemistry in middle education in Algeria relies on explaining all physical and chemical transformations using models. It would have been appropriate for the student to first recognize a variety of changes surrounding him in his daily life, then link them to changes in energy—things that are tangible and visible to the student at this stage of life—before moving on to explanations using models.

For this reason, we proposed a chemistry content based on energy as an entry point for teaching chemistry in Algerian middle education, and in this research we sought to determine the effectiveness of this designed content on the achievement of middle school students in Algeria.

Hypotheses: The research objectives are to test the following null hypotheses:

- There are no statistically significant differences at the 0.01 significance level between the mean achievement of the experimental group students and the mean achievement of the control group students.

- There are no statistically significant differences at the 0.01 significance level between the mean achievement of males in the experimental group and the mean achievement of females in the experimental group.

- There is no statistically significant correlation between the student achievement variable and the curriculum variable.

Importance of the Study: This research helps:

- **Chemistry curriculum planners:** by providing them with the most important concepts and approaches used in teaching chemistry in Algerian middle education.

- **Chemistry teachers and inspectors:** by providing them with revised chemistry content, as well as strategies for lesson planning and teaching strategies that assist them.

- **Researchers:** by opening new perspectives for experimenting with, evaluating, and proposing chemistry curricula for other levels, as well as other educational subjects.

Research Terms:

- **Concept of lesson planning:** Ramzi (2006) provides the following definitions:

  - Abdallah Abd Al-Da'im defines it as: drawing up the educational policy in its complete form, a plan that should be based on a comprehensive understanding of the demographic situations of countries, labor energy conditions, economic, educational, and social conditions.

  - Shibl Badran defines it as: predicting the course of the future in education and controlling it in order to achieve balanced educational development, optimal use of available human and financial resources, and linking educational development with comprehensive economic and social development.

  - Mohamed Seif Al-Din Fahmi defines it as: the continuous organized process that includes methods of social research and the principles and methods of education, administration, economics, and finance, with the aim that students receive adequate education with clear objectives.

- **Developed content:** The proposed content for teaching after undergoing processes of adjustment, development, or change.

- **Middle education stage:** The second stage after elementary education, lasting four years, divided into three phases: the adaptation stage (first year), the support and deepening stage (second and third years), and the guidance stage (fourth year). Student ages range between eleven (11) and sixteen (16) years.

- **Chemistry subject:** The content devoted to studying matter in terms of its properties, structure, composition, behavior, reactions and interactions, and its applications in daily life.

Research Methodology and Procedures:

- **Research population and sample:**

The research population includes all first- and second-year students in middle schools in Medea Province, Algeria, at the time of the study.

A random sample of one hundred fifty (150) first- and second-year middle school students was selected, divided into a control group and an experimental group.

The control group included seventy-one (71) students: thirty-four (34) males and thirty-seven (37) females. The experimental group included seventy-nine (79) students: forty (40) males and thirty-nine (39) females, as shown in the following table:

	Experimental group	**Control group**
	Total	Males
First year	38	20
Second year	41	20
Total	79	40

Table (01): Distribution of the research sample students across the first and second year of middle school.

- **Research tools:** To verify the research hypotheses, we used the following tools:

1. **Preparation of chemistry content based on the concept of energy:**

○ *First year of middle school:* We propose teaching physical changes using experiments that demonstrate these changes and link them to changes in temperature, i.e., energy changes, in line with the chosen approach. The current Algerian chemistry curriculum focuses only on changes of state (between solid, liquid, and gaseous states), while physical change involves changes in the appearance of matter, taste, color, magnetic state, etc. We ensured that these experiments were drawn from the student's daily life and used non-toxic materials, as shown in the following table:

Unit	**Educational units**	**Teaching/learning procedures**	**Number of sessions**	**Educational objectives**
Physical change	• Heating paraffin • Heating glass	1	- Recognize a variety of chemical materials (paraffin, glass, marble, platinum) and describe them (hardness, color, smell, density, melting point). - Identify physical changes and link them to changes in temperature. - Verify the law of conservation of mass in physical change.	

Unit	Educational units	Teaching/learning procedures	Number of sessions	Educational objectives
	• Heating marble • Heating a platinum wire	1		

Table (02): Proposed educational units for teaching first-year middle school students.

- *Second year of middle school:* We include experiments covering most types of chemical reactions: combination, decomposition, single replacement, double replacement, and combustion, to help students recognize a considerable number of chemical substances and their physical and chemical properties, and link these reactions with changes in temperature and energy. Since the current Algerian curriculum covers only a few substances and reactions, additional experiments should be introduced—color changes, disappearance and appearance of substances, formation of precipitates—because at this age students depend on sensory observation and description. We ensured that the selected substances are colored and that their reactions yield observable products, making them suitable for the students' age. See the following table:

Unit	Educational units	Teaching/learning procedures	Number of sessions	Educational objectives
Chemical change	Combination of elements or compounds to form new substances	• Combination of iron and sulfur • Combination of iodine and aluminum	1	- Recognize chemical changes and link them to changes in energy. - Recognize a variety of chemical substances and describe them. - Identify most types of chemical changes (combination, decomposition, single replacement, double replacement, combustion). - Understand that substances react (combine, decompose, burn) to produce new substances different from the starting materials in a chemical transformation. - Express reactions using word equations, then symbols.
	• Combination of copper and oxygen • Heating magnesium ribbon	1		
	Decomposition of compounds to form new compounds	• Heating sugar • Heating copper carbonate • Heating mercury oxide	1	

Unit	Educational units	Teaching/learning procedures	Number of sessions	Educational objectives
	Combustion of substances to form new substances	• Combustion of hydrogen • Combustion of carbon	1	
	• Combustion of propane • Combustion of magnesium	1		

Table (03): Proposed educational units for teaching chemistry to second-year middle school students.

2. **Preparation of lesson cards:** The researchers prepared cards for applying the selected educational units. These cards include objectives to be achieved by the teacher at the end of the session, necessary tools, laboratory safety precautions, class activities, and the final blackboard summary, based on educational literature on lesson planning.

3. **Preparation of a teacher's guide:** Lesson cards were accompanied by a guide designed to help teachers implement this curriculum. It includes educational objectives, key concepts teachers should master, and clarifications on experiments and materials used.

4. **Preparation of an achievement test:** Two tests were prepared, one for each year, each including multiple-choice questions and one open question requiring writing equations. The aim was to measure student achievement after applying the proposed curriculum lessons. These were applied to both the experimental and control groups.

- **Validity and reliability of the test:** The achievement tests were validated by presenting them to chemistry teachers in middle education and specialists in chemistry education. Some modifications were made based on reviewers' recommendations.

Statistical Processing:

To verify the previous hypotheses, we used the independent samples *t*-test to compare two independent groups. According to Al-Munizil (p. 233), the assumptions of the independent samples *t*-test include: random sampling, normality of the two populations, independence of observations, random distribution of samples into groups, and equality of population variances. All assumptions can be confirmed through researcher procedures, except the last, which is checked using a homogeneity test (Levene's test). We also used Pearson's correlation coefficient to test the relationship between curriculum and achievement.

Results and Discussion:

Study Results and Discussion:

First Year of Middle School:

1- There are no statistically significant differences at the significance level of 0.01 between the average achievement of students in the experimental group and the average achievement of students in the control group in the first year of middle school.

By applying the Student's *t* test for independent samples, we obtain the following results:

First Year	Sample Size	Mean	Standard Deviation	Standard Error of the Mean
Academic Achievement – Experimental	38	15.53	3.85	.62

First Year	Sample Size	Mean	Standard Deviation	Standard Error of the Mean
Academic Achievement – Control	33	10.79	3.84	.67

Levene's Test for Homogeneity of Variance	*t* Test for Equality of Means	95% Confidence Interval
F	Sig.	*t*
Academic Achievement – Equal Variances Assumed	.00	.975
Academic Achievement – Equal Variances Not Assumed	5.18	67.65

Table (04): Student's *t* test results for the achievement test for first-year middle school students

Levene's test for homogeneity of variance indicates that the value of F is not statistically significant at the 0.01 significance level, which means there is homogeneity in variance. Therefore, we select the *t* test for equal variances. Looking at the results of the *t* test for equality of variances, it equals 5.18 with 69 degrees of freedom, which is statistically significant at the 0.01 level. This means that there are statistically significant differences at the 0.01 significance level. Considering the means, the experimental group had a mean of 15.53, while the control group had a mean of 10.79, meaning the differences are in favor of the experimental group. From all the above, there are statistically significant differences between the achievement of the experimental group and the control group in the first year of middle school, in favor of the experimental group.

2- There are no statistically significant differences between the achievement of males in the first year of middle school and females of the same year.

By applying the Student's *t* test for independent samples, we obtain the following results:

First Year	Sample Size	Mean	Standard Deviation	Standard Error of the Mean
Academic Achievement – Females	18	16.11	3.18	.75
Academic Achievement – Males	20	15.00	4.38	.98

Levene's Test for Homogeneity of Variance	*t* Test for Equality of Means	95% Confidence Interval
F	Sig.	*t*
Academic Achievement – Equal Variances Assumed	2.41	.129
Academic Achievement – Equal Variances Not Assumed	.90	34.54

Table (05): Student's *t* test results for the achievement test of students in the experimental group for the first year of middle school

Levene's test for homogeneity of variance indicates that the value of F is not statistically significant at the 0.01 significance level, which means there is homogeneity in variance. Therefore, we select the *t* test for equal variances. Looking at the *t* test results for equal variances, it equals 0.89 with 36 degrees of freedom, which is not statistically significant at the 0.01 level. Thus, there are no statistically significant differences between the achievement of males and females in the first year of middle school.

3- There is no statistically significant correlation between the achievement of first-year middle school students and the proposed curriculum for the same year.

By applying Pearson's correlation test, we obtain the following results:

Variable	Academic Achievement	Curriculum Variable
Academic Achievement	Pearson Correlation = 1	.529**
	Sig. = .000	
	N = 71	N = 71
Curriculum Variable	Pearson Correlation = .529**	1
	Sig. = .000	
	N = 71	N = 71

Table (06): Pearson's correlation test results for the achievement test of first-year middle school students

From the table, the correlation coefficient equals 0.529, which means there is a moderate positive correlation between the achievement variable and the curriculum variable. The probability was 0.000, meaning this correlation is statistically significant. Thus, there is a moderate positive correlation between the achievement of first-year middle school students and the proposed curriculum for the same year at the 0.01 significance level.

Second Year of Middle School:

1- There are no statistically significant differences at the 0.01 significance level between the average achievement of students in the experimental group and the average achievement of students in the control group in the second year of middle school.

By applying the Student's *t* test for independent samples, we obtain the following results:

Group	Sample Size	Mean	Standard Deviation	Standard Error of the Mean
Academic Achievement – Experimental	41	16.6463	2.54029	.39673
Academic Achievement – Control	38	13.4474	2.13652	.34659

Levene's Test for Homogeneity of Variance	*t* Test for Equality of Means	95% Confidence Interval
F	Sig.	*t*
Equal Variances Assumed	3.322	.072
Equal Variances Not Assumed	6.072	76.306

Table (07): Student's *t* test results for the achievement test of second-year middle school students

Levene's test for homogeneity of variance indicates that the value of F is not statistically significant at the 0.01 significance level, which means there is homogeneity in variance. Therefore, we select the *t* test for equal variances. Looking at the value of *t* for equal variances, it equals 6.033 with 77 degrees of freedom, which is statistically significant at the 0.01 level. This means there are statistically significant differences at the 0.01 level. Considering the means, the experimental group had a mean of 16.64, while the control group had a mean of 13.44, which means the differences are in favor of the experimental group. From all the above, there are statistically significant differences between the achievement of the experimental group and the control group in the second year of middle school, in favor of the experimental group.

2- There are no statistically significant differences between the achievement of males in the second year of middle school and females of the same year.

By applying the Student's *t* test for independent samples, we obtain the following results:

Second Year	**Sample Size**	**Mean**	**Standard Deviation**	**Standard Error of the Mean**
Academic Achievement – Males	20	16.2000	2.72609	.60957
Academic Achievement – Females	21	17.0714	2.33605	.50977

Levene's Test for Homogeneity of Variance	***t* Test for Equality of Means**	**95% Confidence Interval**
F	Sig.	*t*
Equal Variances Assumed	.960	.333
Equal Variances Not Assumed	-1.097	37.462

Table (08): Student's *t* test results for the achievement test of students in the experimental group for the second year of middle school

Levene's test for homogeneity of variance indicates that the value of F is not statistically significant at the 0.01 level, which means there is homogeneity in variance. Therefore, we select the *t* test for equal variances. Looking at the value of *t* for equal variances, it equals -1.101 with 39 degrees of freedom, which is not statistically significant at the 0.01 level. Thus, there are no statistically significant differences between the achievement of males and females in the second year of middle school.

3- There is no statistically significant correlation between the achievement of second-year middle school students and the proposed curriculum for the same year.

By applying Pearson's correlation test, we obtain the following results:

Variable	**Academic Achievement**	**Curriculum Variable**
Academic Achievement	Pearson Correlation = 1	.567**
	Sig. = .000	
	N = 79	N = 79
Curriculum Variable	Pearson Correlation = .567**	1

Variable	Academic Achievement	Curriculum Variable
	Sig. = .000	
	N = 79	N = 79

Table (09): Pearson's correlation test results for the achievement test for second-year middle school students

From the table, the correlation coefficient equals 0.567, meaning that there is a moderate positive correlation between the achievement variable and the curriculum variable. The probability was 0.000, which means that this correlation is statistically significant. Thus, there is a moderate positive correlation between the achievement of second-year middle school students and the curriculum variable for the same year at the 0.01 significance level.

Interpretation of the Results:

From the above, we find statistically significant differences at the 0.01 significance level between the achievement of the experimental group and the achievement of the control group, and these differences are in favor of the experimental group in both the first and second years of middle school in Algeria. This is attributed to the change in the teaching approach of chemistry from a model-based approach to an energy-based approach, meaning that the new approach has a positive effect on students' achievement in middle school in Algeria.

There are no statistically significant differences between the achievement of males in the experimental group and the achievement of females in the same group in both the first and second years of middle school. This means that the chosen approach to teaching chemistry in middle school has the same effect on both females and males, which supports its use in Algerian middle schools since they are mixed schools.

There is a positive correlation between the achievement variable and the curriculum variable, and this positive correlation is statistically significant at the 0.01 level. This means that the improvement in students' achievement results was associated with the change in the curriculum, that is, the change in the teaching approach of chemistry in middle school.

Research Proposals:

1. Valuing the results of researchers in developing and revising curricula, and taking into account the results they achieve.
2. Carrying out periodic reforms of curricula in various subjects in order to keep pace with all developments in various fields, as well as keeping pace with other countries and their advanced curricula.
3. Focusing on the educational content of subjects and giving it importance.
4. Applying the proposed curriculum to larger samples and in various regions of the country.
5. Including units in the chemistry curriculum that rely on energy as an entry point to learning.

Findings

1. Improved Achievement:
- The experimental group's performance showed statistically significant improvement over the control group at the 0.01 significance level.
2. Positive Correlation:
- A strong positive correlation was found between the achievement scores of students and the energy-based curriculum design, confirming its pedagogical impact.
3. Curriculum Relevance:
- Teachers reported that the integration of energy as a central theme provided coherence across topics, making chemistry more relevant to everyday life and other sciences.
4. Scalability:
- Results suggest that the proposed approach can be effectively scaled to larger samples and implemented in diverse Algerian educational contexts.

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Conflict of Interest

The author declares no conflict of interest regarding the publication of this article.

Ethical Considerations

The study followed all ethical guidelines applicable to educational research. Participation of students was voluntary, and informed consent was obtained from both students and their parents/guardians. The anonymity and confidentiality of participants were strictly maintained. The research design and data collection procedures were reviewed and approved by the Laboratory of Science Didactics' internal ethics review board.

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