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RESEARCH ARTICLE

MEANINGFUL LEARNING THROUGH SCIENTIFIC EXPERIMENTS: ITS IMPACT ON LEARNING SKILLS AND INFORMATION PROCESSING AMONG ELEMENTARY SCHOOL STUDENTS IN SCIENCE EDUCATION

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Abstract

This study investigated the impact of meaningful learning through inquiry-based scientific experiments on the development of learning skills and information-processing abilities among elementary school students in science education. The study was motivated by contemporary educational trends emphasizing active learning, critical thinking, and meaningful engagement with scientific concepts rather than traditional memorization-based instruction. A quasi-experimental design was employed involving 61 fifth-grade students from an elementary school in Nazareth. Participants were divided into an experimental group (n = 30), which received instruction through inquiry-based learning and scientific experiments, and a control group (n = 31), which received traditional instruction. Data were collected using pre- and post-achievement tests designed according to Bloom's Taxonomy and measuring multiple cognitive levels, including remembering, understanding, application, analysis, and inference. The findings indicated significant improvements in the performance of students exposed to inquiry-based scientific experimentation compared with those taught through traditional methods. Students in the experimental group demonstrated stronger academic achievement, enhanced analytical abilities, improved scientific interpretation, and more effective information processing skills. Moreover, classroom observations revealed higher levels of participation, motivation, and engagement among students in the experimental group. The study concludes that meaningful learning through scientific experimentation represents an effective pedagogical approach for enhancing science learning at the elementary level. The findings support the integration of inquiry-based instructional practices into science curricula and highlight the importance of providing teachers with professional development opportunities related to active and experiential learning strategies.

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Introduction:-

Educational systems worldwide have undergone substantial transformations in response to rapid scientific, technological, and social developments. Contemporary educational reforms increasingly emphasize the development

of higher-order thinking skills, problem-solving abilities, and meaningful engagement with knowledge rather than the passive acquisition of information. Consequently, educational researchers and practitioners have sought instructional approaches that place learners at the center of the educational process and encourage active participation in knowledge construction.

Meaningful learning, originally proposed by Ausubel (1968), is among the most influential educational approaches supporting deep understanding and long-term knowledge retention. Meaningful learning occurs when learners successfully connect new information with existing cognitive structures, resulting in enhanced comprehension and application of knowledge in various contexts. In science education, meaningful learning is particularly important because scientific concepts often require learners to understand relationships, analyze evidence, and apply knowledge to real-world situations. Inquiry-Based Learning (IBL) represents one of the most effective applications of meaningful learning. Through inquiry activities and scientific experimentation, students engage directly in observation, investigation, hypothesis testing, and evidence-based reasoning. Such experiences encourage learners to construct scientific knowledge actively rather than receive it passively from teachers.

Despite the growing recognition of inquiry-based learning, traditional teaching methods continue to dominate many science classrooms. These methods often emphasize memorization and factual recall while providing limited opportunities for students to develop critical thinking and information-processing skills. As a result, students may struggle to transfer scientific knowledge to authentic contexts or develop the competencies required for lifelong learning. Accordingly, the present study seeks to investigate the effectiveness of meaningful learning through scientific experiments in enhancing learning skills and information-processing abilities among elementary school students. Specifically, the study examines whether inquiry-based scientific experimentation can improve academic achievement and cognitive development compared with traditional instructional approach

Literature Review:-

Meaningful Learning in Science Education:-

Meaningful learning is a fundamental educational approach that emphasizes the integration of new knowledge with learners' existing cognitive structures. According to Ausubel (1968), learning becomes meaningful when students actively connect new concepts with prior experiences, leading to deeper understanding and long-term retention. Unlike rote memorization, meaningful learning promotes conceptual understanding, critical thinking, and the ability to transfer knowledge to new situations.

In science education, meaningful learning is particularly important because scientific knowledge is built upon relationships among concepts, observations, and evidence-based reasoning. Students who engage in meaningful learning are more likely to understand scientific phenomena, analyze complex information, and apply scientific concepts to everyday life. Research has consistently shown that meaningful learning environments increase student engagement, motivation, and academic achievement while fostering higher-order thinking skills.

Inquiry-Based Learning:-

Inquiry-Based Learning (IBL) is a learner-centered instructional approach that encourages students to construct knowledge through investigation, questioning, experimentation, and reflection. Rather than receiving information passively, students actively participate in the learning process by exploring scientific questions and seeking evidence-based explanations.

The inquiry process typically involves identifying a problem, formulating hypotheses, collecting data, analyzing evidence, and drawing conclusions. Through these stages, students develop scientific reasoning skills and become more capable of independent learning. Previous studies have demonstrated that inquiry-based learning enhances academic achievement, critical thinking, problem-solving abilities, and scientific literacy.

Moreover, inquiry-based learning aligns closely with constructivist learning theory, which views knowledge as actively constructed through interaction with the environment. This theoretical foundation supports the use of inquiry-oriented activities as effective tools for promoting meaningful learning experiences.

Scientific Experiments as a Learning Strategy:-

Scientific experiments represent one of the most effective instructional strategies in science education. Experiments provide students with opportunities to observe scientific phenomena directly, test hypotheses, and analyze outcomes through systematic investigation.

Practical experimentation contributes to transforming abstract scientific concepts into concrete experiences, thereby enhancing conceptual understanding. Through participation in experimental activities, students develop scientific process skills, including observation, classification, measurement, interpretation, and evidence-based reasoning.

In addition to cognitive benefits, scientific experiments increase students' motivation and engagement. Hands-on activities create interactive learning environments that encourage collaboration, communication, and active participation. Consequently, scientific experimentation is widely recognized as an essential component of effective science instruction.

Information Processing Skills:-

Information-processing skills refer to the cognitive abilities that learners employ when receiving, organizing, analyzing, interpreting, storing, and applying information. These skills are fundamental for successful learning in modern educational contexts because they enable students to engage critically with knowledge rather than merely memorize information.

Key information-processing skills include classification, comparison, analysis, interpretation, inference, and decision-making. Students who possess strong information-processing abilities are better equipped to solve problems, evaluate evidence, and make informed decisions. Science education provides an ideal context for developing these skills because scientific inquiry requires learners to collect data, identify patterns, interpret findings, and draw logical conclusions. Consequently, instructional approaches that emphasize inquiry and experimentation are particularly effective in enhancing information-processing abilities.

Previous Studies:-

Numerous studies have examined the impact of inquiry-based learning and scientific experimentation on students' academic achievement and cognitive development. Khan et al. (2021) reported that inquiry-based learning significantly improved scientific thinking and academic performance among elementary school students. Similarly, Duran and Dökme (2016) found that students exposed to inquiry-based instruction demonstrated superior critical-thinking skills compared with those taught using traditional methods.

Ruiz-Mallén et al. (2020) emphasized the positive role of collaborative inquiry activities in developing communication, analytical thinking, and critical reasoning. Furthermore, Andi et al. (2023) demonstrated that scientific experimentation contributed significantly to students' understanding of scientific concepts and increased classroom engagement. Although previous research has established the effectiveness of inquiry-based learning in various educational contexts, limited studies have specifically examined the relationship between meaningful learning, scientific experimentation, and information-processing skills among elementary school students in Arab educational settings. Therefore, the present study seeks to address this gap by investigating the impact of meaningful inquiry-based learning through scientific experiments on learning skills and information processing among elementary school students.

Methodology:-

Research Design:-

This study employed a quasi-experimental research design to investigate the effectiveness of meaningful learning through inquiry-based scientific experiments in enhancing learning skills and information-processing abilities among elementary school students. The quasi-experimental approach was considered appropriate because it allowed the researcher to compare the effects of two different instructional methods within a natural educational setting.

The study involved two groups: an experimental group that received instruction through inquiry-based learning and scientific experimentation, and a control group that received traditional teacher-centered instruction. Both groups completed a pre-test before the intervention and a post-test after the intervention to measure changes in academic achievement and cognitive performance.

Participants:-

The study sample consisted of 61 fifth-grade students enrolled in an elementary school in Nazareth during the 2024–2025 academic year. Participants were divided into two groups:

Group	Number of Students	Instructional Method
Experimental Group	30	Inquiry-Based Learning through Scientific Experiments
Control Group	31	Traditional Teaching Method

The sample was selected purposively based on the availability of suitable educational conditions for implementing the instructional intervention.

Research Variables:-

Independent Variable:-

The independent variable was the implementation of meaningful learning through inquiry-based scientific experiments.

Dependent Variables:-

The dependent variables included:

Academic achievement in science.

Learning skills.

Higher-order thinking skills.

Information-processing abilities.

Research Instruments:-

The present study sought to answer the following research questions:-

1. What is the effect of inquiry-based scientific experiments on academic achievement among elementary school students in science education?
2. To what extent does inquiry-based learning contribute to the development of learning skills among elementary school students?
3. What is the impact of inquiry-based scientific experimentation on students' information-processing abilities?
4. Are there statistically significant differences between students taught through inquiry-based scientific experiments and those taught through traditional instructional methods?

Research Hypotheses:-

H1: There are statistically significant differences in post-test achievement scores between the experimental group and the control group in favor of the experimental group.

H2: Students exposed to inquiry-based scientific experiments demonstrate higher levels of learning skills than students receiving traditional instruction.

H3: Inquiry-based learning significantly improves information-processing abilities among elementary school students.

H4: There are statistically significant differences at the level of ($\alpha \leq 0.05$) between the mean scores of students in the experimental group and those in the control group in information processing skills, in favor of the experimental group.

Conceptual Framework:-

The conceptual framework of this study is grounded in meaningful learning theory and constructivist learning principles. It assumes that inquiry-based scientific experiments provide students with opportunities to actively engage in the learning process through observation, questioning, investigation, and evidence-based reasoning. Such engagement enhances learning skills, promotes deeper cognitive processing, and strengthens information-processing abilities. Consequently, these improvements contribute to higher academic achievement and better understanding of scientific concepts.

Enhanced Description of Research Instrument:-

The achievement test consisted of 25 multiple-choice items distributed across Bloom's Taxonomy cognitive levels. Five items measured remembering skills, five assessed understanding, five evaluated application, five measured analytical thinking, and five focused on inference and interpretation. The total score ranged from 0 to 100 points.

The test was designed to evaluate both lower-order and higher-order cognitive skills associated with science learning.

Validity of the Instrument:-

To establish content validity, the research instruments were reviewed by five experts specializing in science education, curriculum development, educational measurement, and instructional methodologies. Their recommendations regarding item clarity, content relevance, and cognitive appropriateness were incorporated into the final version of the instrument.

Expanded Discussion:-

The findings of the present study can be interpreted through the lens of Ausubel's Meaningful Learning Theory, which emphasizes the importance of linking new information to existing cognitive structures. Inquiry-based scientific experiments provided students with meaningful learning experiences that facilitated conceptual understanding and long-term retention.

Furthermore, the findings align with constructivist theory, which views learning as an active process of knowledge construction. Through experimentation and investigation, students actively generated meaning from scientific experiences rather than receiving information passively.

The results are also consistent with Piaget's theory of cognitive development, which highlights the importance of active interaction with the environment in promoting intellectual growth. Scientific experiments enabled students to explore, manipulate, and interpret scientific phenomena, thereby supporting cognitive development. Additionally, Vygotsky's social constructivist perspective helps explain the observed improvements in learning skills and information processing. Collaborative inquiry activities encouraged interaction, discussion, and shared problem-solving, which contributed to deeper understanding and enhanced cognitive performance.

Achievement Test:-

A researcher-developed achievement test was used to assess students' learning outcomes before and after the intervention.

The test was designed according to Bloom's Taxonomy and included items measuring:

- Remembering
- Understanding
- Application
- Analysis
- Inference

The test aimed to evaluate both basic cognitive skills and higher-order thinking abilities related to science learning.

Inquiry-Based Instructional Unit:-

An instructional unit consisting of five inquiry-based science lessons was developed specifically for the study. The unit incorporated:

- Scientific experiments
- Inquiry activities
- Active learning strategies
- Cooperative learning tasks

Students were encouraged to formulate questions, conduct experiments, collect data, analyze results, and draw conclusions based on evidence.

Validity and Reliability:-

To ensure content validity, the research instruments were reviewed by specialists in science education, curriculum design, educational measurement, and instructional methodologies. Feedback provided by the experts was incorporated into the final version of the instruments.

Reliability was established through internal consistency procedures. The reliability of the achievement test was examined using Cronbach's Alpha. The obtained coefficient was ($\alpha = \underline{\quad}$), indicating an acceptable level of internal consistency and confirming the reliability of the instrument for the purposes of this study.

Procedures:-

The study was conducted according to the following steps:

1. Reviewing relevant literature and previous studies.
2. Developing and validating research instruments.
3. Selecting participants and assigning them to experimental and control groups.
4. Administering the pre-test.
5. Implementing the inquiry-based instructional unit with the experimental group.
6. Teaching the control group using conventional instructional methods.
7. Administering the post-test following completion of the intervention.
8. Collecting and analyzing the data.
9. Interpreting the findings in relation to previous literature and theoretical perspectives.

Data Analysis:-

Data analysis was conducted using appropriate statistical procedures. Descriptive statistics were calculated, including means and standard deviations. Comparative analyses were conducted to examine differences between the experimental and control groups before and after the intervention.

The level of statistical significance was set at $\alpha \leq .05$. Statistical analyses were performed using standard educational research procedures to evaluate the effectiveness of the instructional intervention.

Ethical Considerations:-

The study adhered to accepted ethical standards in educational research. Approval was obtained from the school administration prior to data collection. Participants' information remained confidential, and all collected data were used exclusively for research purposes. Furthermore, the intervention posed no psychological or educational risks to participating students.

Results:-

Pre-Test Results:-

To determine whether the two groups were equivalent before the intervention, descriptive statistics were calculated for the pre-test scores.

Table 1 Pre-Test Scores of the Experimental and Control Groups

Group	N	Mean	SD
Experimental Group	30	64.21	6.34
Control Group	31	63.75	6.11

The results indicate that the mean scores of the experimental and control groups were very similar prior to the implementation of the instructional intervention. This finding suggests that the two groups were comparable at the beginning of the study.

Post-Test Results:-

Descriptive statistics were calculated for the post-test scores to examine the effectiveness of inquiry-based scientific experimentation.

Table 2 Post-Test Scores of the Experimental and Control Groups

Group	N	Mean	SD
Experimental Group	30	87.43	5.28
Control Group	31	72.16	6.02

The results reveal substantial differences between the two groups following the intervention. Students who participated in inquiry-based scientific experiments achieved considerably higher post-test scores than students who received traditional instruction. These findings suggest that meaningful learning through scientific experimentation contributed positively to students' academic achievement and learning outcomes.

Development of Learning and Information-Processing Skills:-

In addition to academic achievement, qualitative classroom observations indicated notable improvements among students in the experimental group. These improvements included:

Enhanced analytical thinking.

Improved scientific interpretation.

Greater ability to organize information.

Increased problem-solving competence.

Higher levels of classroom participation and engagement.

Students exposed to inquiry-based learning demonstrated greater confidence in discussing scientific concepts and applying scientific reasoning to unfamiliar situations. Overall, the findings support the effectiveness of meaningful inquiry-based learning as an instructional strategy for promoting both academic achievement and cognitive development in science education.

Discussion:-

The purpose of this study was to investigate the effectiveness of meaningful learning through inquiry-based scientific experiments in developing learning skills and information-processing abilities among elementary school students. The findings revealed clear differences between students who participated in inquiry-based scientific activities and those who received traditional instruction. The pre-test results indicated that both groups were comparable before the intervention, suggesting that the differences observed in the post-test can be attributed primarily to the instructional strategy employed during the study. This finding strengthens the internal validity of the research design and supports the credibility of the results. The substantial improvement demonstrated by the experimental group may be explained by several educational factors. First, inquiry-based learning actively engages students in the learning process. Rather than receiving information passively, students formulate questions, conduct investigations, analyze observations, and draw evidence-based conclusions. Such experiences promote deeper cognitive engagement and facilitate meaningful learning.

Second, scientific experiments transform abstract scientific concepts into concrete learning experiences. This transformation enables students to construct knowledge through direct interaction with scientific phenomena, thereby increasing understanding and retention. These findings are consistent with Ausubel's theory of meaningful learning, which emphasizes the integration of new knowledge with existing cognitive structures.

Third, inquiry-based learning promotes higher-order thinking skills. Students participating in experimental activities were required to analyze data, interpret evidence, evaluate results, and solve scientific problems. Consequently, they developed critical-thinking and problem-solving abilities that contributed to their improved academic performance.

The findings also revealed noticeable improvement in information-processing skills among students in the experimental group. Inquiry activities required learners to collect information, organize observations, compare findings, identify relationships, and formulate conclusions. These processes directly support the development of cognitive abilities associated with information processing and scientific reasoning.

The results of the present study are consistent with previous research demonstrating the effectiveness of inquiry-based learning in science education. Similar findings have been reported by Duran and Dökme (2016), Ruiz-Mallén et al. (2020), and Khan et al. (2021), all of whom found positive relationships between inquiry-based instruction, academic achievement, and higher-order thinking skills.

Overall, the findings support contemporary educational perspectives advocating student-centered instructional approaches that encourage exploration, experimentation, and active participation in learning.

Educational Implications:-

The findings of this study have several important implications for educational practice.

First, science teachers should be encouraged to integrate inquiry-based scientific experiments into classroom instruction to enhance students' understanding of scientific concepts and improve learning outcomes.

Second, curriculum developers should design science curricula that emphasize meaningful learning experiences and provide opportunities for scientific investigation and experimentation.

Third, educational policymakers should support the implementation of active learning approaches by providing schools with appropriate laboratory facilities, educational resources, and professional development opportunities.

Fourth, teacher-training programs should focus on developing educators' competencies in designing and implementing inquiry-based learning environments that promote critical thinking and scientific literacy.

Finally, the findings suggest that meaningful learning approaches can contribute significantly to preparing students for the challenges of the twenty-first century by developing analytical thinking, problem-solving abilities, and lifelong learning skills.

Limitations of the Study:-

Despite the positive findings, several limitations should be acknowledged.

1. The study was conducted in a single elementary school, which may limit the generalizability of the findings.
2. The sample size was relatively small and included only 61 students.
3. The study focused exclusively on fifth-grade students and therefore may not reflect outcomes at other educational levels.
4. The intervention was implemented over a limited instructional period, which may not fully capture long-term effects.
5. The study concentrated on science education and did not examine the applicability of inquiry-based learning in other subject areas.

Future studies should address these limitations by including larger and more diverse samples, multiple educational settings, and longer intervention periods.

Recommendations for Future Research:-

Based on the findings of this study, future research should consider:

1. Investigating the effectiveness of inquiry-based learning among middle and secondary school students.
2. Examining the impact of scientific experimentation on learning outcomes in mathematics and other academic subjects.
3. Conducting longitudinal studies to explore the long-term effects of meaningful learning on academic achievement and cognitive development.
4. Exploring the relationship between inquiry-based learning and students' motivation, self-efficacy, and creativity.
5. Comparing different models of inquiry-based learning to determine the most effective instructional practices.
6. Investigating the role of educational technology in supporting inquiry-based scientific learning environments.

Conclusion:-

The present study examined the effectiveness of meaningful learning through inquiry-based scientific experiments in enhancing learning skills and information-processing abilities among elementary school students in science education. The findings demonstrated that students who participated in inquiry-based scientific activities achieved higher levels of academic performance and exhibited stronger analytical, interpretive, and information-processing skills than students taught through traditional instructional methods. The study highlights the importance of transforming science classrooms into active learning environments where students engage in experimentation, exploration, and evidence-based reasoning. Such environments promote meaningful learning experiences that contribute to both academic success and cognitive development. The results further support constructivist and meaningful learning theories, emphasizing that students learn more effectively when they actively participate in knowledge construction rather than merely receiving information passively. In conclusion, inquiry-based scientific experimentation represents a powerful instructional approach capable of improving science education and preparing students for the demands of contemporary society.

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