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# Enhancing Exploratory Thinking Through NGSS-Aligned Engineering and Science Practices: A Quasi-Experimental Study Among Saudi Elementary Students

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## ABSTRACT

This study examines the effectiveness of exploratory activities grounded in the engineering and science practices of the Next Generation Science Standards (NGSS) in fostering exploratory thinking among elementary students in Mecca, Saudi Arabia. Utilizing a quasi-experimental design, the research involved 64 fourth-grade female students divided into experimental and control groups. The "Unit of Energy" was restructured to align with NGSS principles, and both a teacher's guide and student activity notebook were developed accordingly. An exploratory thinking test (covering nine cognitive domains) was administered as a pre- and post-test over a six-week intervention period. Results revealed statistically significant improvements in the experimental group's post-test scores across all domains of exploratory thinking compared to the control group. The findings highlight the value of integrating NGSS-aligned exploratory activities in science education and underscore the need to incorporate such practices into teacher preparation programs to strengthen scientific inquiry and critical thinking skills at the elementary level.



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## 1. INTRODUCTION

Science is an analytical subject that relies on the interaction between man and the environment through studying nature. Course designers should utilize knowledge and modern learning technology, such as Virtual Reality (VR) and Augmented Reality (AR), to serve society and solve problems (Omar, 2017; Sharma, 2022). Next Generation Science Standards (NGSS) motivates students to the processes and skills of scientific exploration and data analysis (LaDue & Manning, 2015), especially in the elementary stage, in which they are trained in thinking and behaving like scientists and engineers (Isabelle, 2017). In other words, science learning based on NGSS emphasizes exploring life phenomena by integrating engineering and science practices (SEPs) with scientific content. Instead of mastering learning steps theoretically, students are motivated to practice exploratory activities on real phenomena, including asking questions, solving complex problems, developing hypotheses, designing and conducting experiments, testing and discussing data, constructing arguments, and discussing results (Kuhn *et al*., 2017; Wardani *et al*., 2022).

Some researchers (Krajcik *et al*., 2014) argue that asking questions directs students towards unreachable horizons, allowing them to think and interact with the content, provide solutions, and explain phenomena logically. Accordingly, students need to develop exploratory thinking. The practices of exploration and research skills, generating models, analyzing data, and using statistics and probabilities are effective and common tools in science. However, they are neglected. Several authors recommend including these practices effectively in the content to achieve better results in science teaching and learning (Sneider *et al*., 2014). NGSS-based exploration motivates students to challenge ideas, ask questions, provide and test explanations, and communicate them to others (Wright *et al*., 2024).

The objective of Saudi Vision 2030 concerning education is to provide opportunities, improve the quality of educational outcomes, increase the effectiveness of scientific research, encourage creativity and innovation, develop community partnership, upgrade the capabilities and skills of education personnel, filling the gap between higher education outputs and labor market requirements, develop general education, guide students towards appropriate career options, and provide opportunities to rehabilitate students and move flexibly between different educational paths (Albiladi, 2022; Allmnakrah & Evers, 2020). It could not be achieved by providing a learning environment that triggers student thinking and inquiry. Many studies (Haag & Megowan, 2015; Kuhn *et al*., 2017) demonstrated the need to employ and integrate SEPs into science learning.

Because of education development in Saudi Arabia, the new and translated science courses rely on McGraw-Hill to develop the capabilities, innovations, and skills of students. The literature demonstrated the poor level of Saudi students. For example, some reports (Jensen *et al*., 2014) reported a low level of students on the 2007 and 2011 tests. These findings matched the other reports (Hole *et al*., 2018) concerning the low level of students in performing the TIMSS test in 2015. Moreover, some reports (Iordanou & Constantinou, 2015) indicated the lack of NGSS indicators in the "Unit of Energy" for the 6th elementary and the 1st and 2nd middle school students. Some reports (Stern & Roseman, 2004) illustrated the low level of the main ideas, SEPs, and comprehensive concepts in the energy domain at the secondary stage physics textbooks. Additionally, some reports (Kang & Lee, 2020) emphasized the reduced availability of SEPs of NGSS in science textbookisss among 1st-grade middle students. Some reports (Weintrop *et al*., 2016) indicated the low level of achievement of NGSS and the 3rd elementary grade, such as using mathematical and computational thinking, building interpretations, designing solutions, and engaging in scientific controversy.

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The present research paper seeks to answer the following main question: "What is the effectiveness of using exploratory activities based on SEPs of NGSS in developing exploratory thinking among elementary students?

The main question is subdivided into the following minor ones: (i) what exploratory activities are based on SEPs of NGSS among 4th-grade elementary students? and (ii) what is the effectiveness of using exploratory activities based on SEPs of NGSS in developing exploratory thinking among 4th-grade elementary students in Mecca, Saudi Arabia?.

The research paper aims to restructure the activities of the "Unit of Energy" for the 4th elementary grade in light of exploratory activities based on SEPs of NGSS, including:

(i) Examine the effectiveness of using exploratory activities in the "Unit of Energy" based on SEPs of NGSS in developing exploratory thinking among 4th-grade elementary students in Mecca, Saudi Arabia.

Significance is in the following:

(i) The present research paper examines NGSS as the latest and most contemporary international standards in science teaching.
(ii) It may benefit curriculum developers to employ NGSS in developing the delivery of science activities in various disciplines (e.g., biology, physics, geoscience, engineering, and technology).
(iii) It tackles exploratory thinking that develops the capabilities of students to research by asking questions about the surrounding environment, thinking about the evidence-interpretation relationship, as well as developing activities to collect, organize, and analyze data.
(iv) It is applied to the elementary stage, in which students are provided with the scientific and practical basics of SEPs.

Subject limitations are in the following:

(i) Activities of the "Unit of Energy" of the science course for the 4th elementary grade (Sayilgan et al., 2022).
(ii) Exploratory thinking test that covers (observation, interpretation, experiment, definition, conclusion, using numbers, classification, hypotheses, and impact of variables).
(iii) Temporal limitations are that the study was applied in the second semester of 2019/2020.
(iv) Human limitations are that a sample of 4th-grade elementary students.

Definitions of terms are in the following:

(i) NGSS are procedurally defined as a set of performance indicators to be achieved by 4th-grade students at the end of the exploratory activities of the "Unit of Energy".
(ii) SEPs-based exploratory activities are scientific activities and experiments, covering the topics of the "Unit of Energy" of the science course for 4th grade in the second semester of 2019/2020.
(iii) Exploratory thinking comprises nine (9) domains that a student performs by employing SEPs of NGSS to reach scientific knowledge or study scientific phenomena included in various activities in the "Unit of Energy" of the 4th-grade science textbook.

NGSS provides a new vision to engage students in SEPs. These practices are the first domain of NGSS. Thus, students integrate into the content and problem-solving by linking theory to practice (Schaben *et al*., 2022).

Scientific activity shows the scientific vision as a set of practices, illustrating those developing theories, illustrations, and finding solutions are a set of activities carried out by scientists and engineers. These practices cover a network of participants and specialized

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methods for research and writing, developing models to represent different systems and phenomena, making inferences, developing tools, and testing hypotheses through experiment or observation (Wang *et al*., 2023). The National Academies Press in 2013 reports several logical justifications for employing SEPs in grades K-12, such as:

(i) Understanding the evolution of scientific knowledge.
(ii) Appreciating a wide range of methods that use exploration, modeling, and interpreting global phenomena.
(iii) Understanding the work of engineers, linking engineering and science, and having a deeper understanding of comprehensive concepts and basic ideas.
(iv) Understanding interconnected concepts and basic ideas of science and engineering.
(v) Arousing students' curiosity and interest, motivating them to pursue studies, and forming positive attitudes.

According to the literature (Lee *et al*., 2013; Andersen *et al*., 2022), the eight SEPs that the framework identified should be mastered by all students are:

(i) Asking questions and defining problems: Students should be able to ask questions about the texts they read, the phenomena they observe, and the conclusions they draw from their models or scientific exploration. For engineering, they should ask questions to define the problem and its constraints.
(ii) Developing and using models: Modeling can begin in the earliest grades, from concrete pictures or physical models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram to illustrate the relations between variables (Acher *et al*., 2007). In engineering, models may be used to analyze a system, test potential solutions, evaluate a design, and communicate its features to others.
(iii) Planning and carrying out investigations: Students should have the opportunity to plan and implement various forms of investigations in grades (K-12) that ranged from those structured by teachers to expose an issue or question that is impossible to explore on their own (e.g., measuring materials' features) to those emerged by their questions.
(iv) Analyzing and interpreting data: Students are expected to expand their capabilities to use a range of tools for graphical representation, visualization, statistical analysis, interpreting data, and using mathematics to represent relationships between variables.
(v) Using mathematical and computational thinking: They are two tools for understanding and representing physical variables and their relationships and predicting physical systems' behavior in various forms, such as analyzing, expressing, and applying data statistically.
(vi) Constructing explanations and designing solutions: Scientific explanations are applications of a particular theory or phenomenon, often depending on a model, including a claim about how two or several variables relate to another variable or a set of variables in response to a question.
(vii) Engaging in argument from evidence: The study of science and engineering should focus on producing and defending a new idea or an explanation of a phenomenon.
(viii) Obtaining, evaluating, and communicating information: Science and engineering education develop students' ability to read and produce domain-specific text.

The National Academies Press in 2012 reports that the development of NGSS provides guidelines to use SEPs, as follows:

(i) Students in grades K-12 should be involved in all eight practices in each academic domain. NGSS identifies the abilities that are expected to be acquired by students at the end of each academic domain (K-2, 3-5, 6-8, and 9- 12). Students' abilities to use these practices increase over time.

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(ii) SEPs grow in complexity and sophistication from one grade to another. Thus, students' abilities should progress as they engage in science learning. For example, the practice of "planning and carrying out investigations" begins at the (K-2) level with guided situations to identify phenomena and to observe, measure, and record outcomes. In the upper elementary grades (3-5), students should be able to plan and implement investigations that are expected to increase, including the complexity of questions and the nature of research.
(iii) Each practice may reflect the nature of science or engineering based on the objectives of the activity, including answering a question (science) and identifying and solving a problem (engineering).
(iv) SEPs represent what students are expected to do. The framework offers suggestions for instruction, such as explorations to solve a problem.
(v) The eight SEPs are overlapped and interrelated. For example, the practice of "asking questions" may lead to the practice of "modeling" or "planning and carrying out investigations," which in turn may lead to "analyzing and interpreting data". The practice of "mathematical and computational thinking" may include some aspects of "analyzing and interpreting data".
(vi) Performance expectations focus on some practice-related abilities. Thus, the framework identifies the appropriate abilities associated with each class.

Several studies examined SEPs based on NGSS. For instance, some reports (Menon & Devadas, 2019) showed the effectiveness of students' engagement in SEPs to develop their understanding of biological concepts, increasing their motivation to learn, and the absence of integration impact of NGSS on student awareness concerning teacher care. Some reports (Mahanal *et al*., 2019) reported students' ability to build and develop models. Some reports (Mintzes *et al*., 2013) focused on developing a scientific activities program in the elementary stage based on quality standards and concluded the achievement of self-efficacy among students, including student responsibility for learning, social interaction, peer evaluation, and self-organization.

Some reports (Bielik *et al*., 2022) found varying degrees of alignment between teachers' performance and classroom learning owing to NGSS objectives. Because misunderstanding the objectives of NGSS makes it difficult to apply these practices, training programs are important for pre-service and in-service teachers. Some reports (Qablan, 2016; Van Driel *et al*., 2001) aimed to identify the potential of science teachers to change their abilities when designing and implementing science lessons. The results indicated how the participants greatly benefited from the training program in designing and implementing lessons based on research and exploration, which affected their students' engagement in SEPs. In contrast, their ability to ask questions and carry out investigations was not at the required level.

Some reports (Sabah *et al*., 2023) developed a unit based on NGSS and its impact on the practices, achievements, and attitudes of 8th-grade students towards sciences in Jordan. The results showed that the degree of inclusion of NGSS in the developed unit was 84%. Most of the participants (73%) adopted the NGSS vision. There are statistically significant differences in the achievement of experimental group students in favor of the post-test. Some reports (Elgendy & Elmeanawy, 2023) indicated the effectiveness of developing the chemistry curriculum for the 1stgrade secondary students in light of the engineering design of NGSS to develop the achievement and SEPs. Some reports (Kang *et al*., 2018) demonstrated the effectiveness of a training program based on NGSS in developing a deep understanding, scientific exploration skills, and scientific controversy among elementary stage science

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teachers. Some reports (Kuhn *et al*., 2017; Darling-Hammond *et al*., 2020) highlighted the effectiveness of students' practice of science practices on increasing a deep understanding of science, developing research and analysis skills, and evaluating information.

Some reports (Bao & Koening, 2019) addressed the development of the physics curriculum at the secondary stage based on NGSS to develop critical thinking and deep understanding. The results revealed that NGSS is not available in the physics curriculum, critical thinking, and deep understanding. some reports (Malkawi & Rababah, 2019) examined the effectiveness of a training program for science teachers in Jordan based on the NGSS in developing SEPs and self-efficacy. Some reports (Kim & Hamdan, 2020) aimed to provide activities based on NGSS to develop SEPs, critical thinking, and scientific interests among elementary students in Saudi Arabia. The results found statistically significant differences between the mean scores of the pre- and post-test of the experimental group in SEPs, critical thinking, and scientific interest, favoring the post-test.

Some reports (Kang *et al*., 2018) aimed to evaluate the results of educational content knowledge and support students in developing SEPs based on the NGSS (Golan Duncan & L. Cavera, 2015; Roseman *et al*., 2017). The results revealed the awareness of teachers of educational content and their ability to support students. Some reports (Malkawi & Rababah, 2018) aimed to verify that the twelfth-gradasaaze teachers in Jordan are utilizing SEPs based on NGSS. The results revealed that science teachers moderately incorporate SEPs in their teaching. In addition, no statistically significant differences between the practices of science teachers in applying SEPs owing to the demographic variables (i.e., specialization, educational qualification, and teaching experience), while there were differences between the practices of science teachers based on gender, favoring females.

Some reports (Christian *et al*., 2021) aimed to identify the level of practicing the NGSS among 64 physics science teachers. The results concluded the poor knowledge of teachers concerning the pivotal ideas of physics based on the NGSS. Although they implemented most of the SEPs, they do not have an adequate understanding of and apply engineering practices. Some reports (Shernoff *et al*, 2017) addressed the impact of the professional development activity of teachers based on NGSS in 15 international schools delivering an American curriculum (Christian *et al*., 2021; McGee & Nutakki, 2017; Mohamad Hasim *et al*., 2022). The study found a statistically significant impact on teachers' understanding of NGSS in all spheres, and improved teachers' practices in the classroom and their collaborative professional practices.

Although the previous studies varied in exploring NGSS, no study has examined the use of exploratory activities based on SEPs in developing exploratory thinking skills for elementary students. Thus, the present research benefited from them in identifying NGSS, how to use them in teaching, and determining the type of SEPs and the appropriate exploratory activities for the elementary stage. It also benefited from literature in developing research tools and materials.

According to the literature (Shamsudin *et al*.,2013), exploration collects information through investigation, including asking questions about phenomena, examining a specific problem, as well as constructing knowledge that requires critical thinking, making observations, doing experiments, reaching conclusions, thinking creatively, and using intuition. Thus, it means understanding the characteristics of science through scientific experimentation. It includes structuring hypotheses, scientific conclusions, drafting scientific interpretations, and providing evidence (Kara & Li, 2011; Pereira *et al*., 2014). As an educational method, exploration is based on facing the student with a problem, allowing self-confrontation, and problem-solving (Téllez, 2021). Several studies aimed to develop

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exploratory thinking skills. For example, several reports (Uyanik & Uyanik, 2024) indicated the effectiveness of a developed unit based on self-learning practices in developing scientific research skills and curiosity among elementary students. Several reports (Al-Alifi et al., 2011) investigated the effect of the coupled-inquiry cycle in the development of exploration skills in science among the 8th-grade students. The results showed statistically significant differences between the arithmetic means of experimental and control groups and the pre-test and post-test in exploration skills, including asking questions, designing experiments, analyzing, and interpreting, as well as the overall skills favoring the experimental group. Moreover, there were no differences in designing experiments and activities, and analysis skills.

Several reports (Ead, 2024) indicated the effectiveness of teaching based on academic achievement, development of scientific research skills, and innovative thinking in physics for secondary students in Dakahlia, Egypt. Several reports (Lin *et al*., 2021) investigated the effect of teaching by using the inquiry wheel model, problem-solving method, developing cognitive achievement traditionally, scientific exploration skills, and motivation for science learning among the 2ndgrade middle students. The results indicated the superiority of the two experimental group students over the control group students. Several reports (Almasri, 2024) analyzed the effect of teachers' usage of the exploration approach in science teaching compared to traditional teaching. The results showed that the use of this approach led to the development of questioning skills and the opportunity for teachers to enhance exploration skills for students. Some reports (Kruit *et al*., 2018; Hong *et al*., 2016) examined the effect of explicit instructions on the acquisition of exploratory thinking skills, Explicit instructions facilitated the acquisition of exploratory skills. Although several previous studies investigated the development of exploratory thinking skills, no study examined the effectiveness of using SEPs of NGSS in developing exploratory thinking, which is the focus of the present research paper.

There is a statistically significant difference at the level of ≤ 0.05 between the mean scores of the experimental groups (that studied exploratory activities using SEPs) and the control group (that studied in the traditional method) in the post-test of exploratory thinking and its sub-domains.

## 2. METHODS

This study utilized the quasi-experimental method based on the control and experimental groups. The population covered elementary students in Mecca. The sample comprised 64 randomly selected 4th-grade elementary female students from two classes in the Thirty-Four Elementary School in Mecca. They were distributed to the experimental and control groups for 2019/2020.

Materials and tools include:

(i) A teacher's guide for the activities of the "Unit of Energy" was based on NGSS after reviewing the related literature (Kara & Li, 2011). It comprised an introduction, a list of SEPs, SEPs implementation principles and guidelines, performance indicators and expected learning outcomes, NGSS-based leaching strategies, evaluation methods, and gradual presentation of the activities in the light of SEPs according to the 5E learning cycle model. The lessons' activities began with an introductory activity by invoking previous knowledge, discussing students, identifying their backgrounds, and writing their answers in the learning schedule. Then, the discovery stage included carrying out the activity either individually or collaboratively, followed by the interpretation stage in which the

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teacher discusses students in their findings, adjusts their error conceptions, and provides support to the groups that have achieved the most appropriate answer and the best forms of investigation and research (Fleeson & Noftle, 2008). Finally, the enrichment and expansion stage included applying knowledge in new and more complex situations. At the end of each lesson, the evaluation process is conducted.

(ii) The student activity notebook included appropriate exploratory activities based on SEPs of NGSS among the 4th-grade elementary students.

(iii) Preparing exploratory activities based on the NGSS

To answer the first question, the author followed these steps:

(i) Reviewing the relevant literature (Kara & Li, 2011; Ladkau et al., 2014).

(ii) Choosing the "Unit of Energy" from the science course for the 4th grade because it is one of the basic ideas of NGSS and in line with the national transformation program the Saudi Vision 2030, which is concerned with energy and its use, preserving, and diversifying sources.

(iii) Determining a set of activities to achieve the objectives of the "Unit of Energy" after reviewing the scientific and educational resources and consulting several specialists in science instruction.

(iv) Making a list of the expected learning performance after conducting exploratory activities based on SEPs of NGSS.

(v) Structuring the selected activities in the light of SEPs, including: Asking verifiable questions and predicting results, Planning and carrying out explorations, Constructing interpretations and providing solutions, Obtaining information from sources, evaluation, and communication, Engaging in an argument from evidence, comparing, and refining these arguments, Using numbers to describe, measure, estimate, and organize data, Using and designing models, such as diagrams, concrete forms, tables, and mathematical expressions, Reading science and engineering texts, including tables, charts, diagrams, and websites to identify the main features of writing and the ability to produce written and illustrated texts using oral presentations (Mewaldt et al., 2008).

This study came out with 37 exploratory activities based on SEPs distributed to the topics of the unit and explained in the student notebook and teacher's guide. They were presented to specialists in science curriculum and instruction, supervisors, and science teachers for the elementary stage. The required modifications were made to facilitate some activities to suit the age group (Lowenhaupt & McNeill, 2019).

The test aimed at ensuring the average acquisition of 4th-grade students of some exploratory thinking skills. It covered some exploration skills indicated as domains in the test, e.g., observation, interpretation, experiment, definition, conclusion, using numbers, classification, hypotheses, and impact of variables (Jepsen et al., 2004). Test items numbered (33 questions) were phrased based on multiple-choice questions. Each one had four options and one score. Thus, the test score ranged (0-33. The test was presented to a group of reviewers to verify its validity. They made some modifications, including the deletion of five items and the rephrasing of some items. Thus, the final form comprised 28 items. After making the required modifications, the test was applied to 30 4th-grade elementary female students in the Thirty-Four Elementary Schools outside the sample to calculate the following:

Test reliability was calculated by re-testing exploratory thinking on the same pilot sample after two weeks. The correlation between the degrees of the two tests was calculated using the Pearson correlation coefficient, as shown in **Table 1**. **Table 1** illustrates that the test is highly reliable. Thus, it can be used to measure exploratory thinking domains.

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For internal consistency, the Pearson correlation coefficient was used to calculate the correlation between the scores of explorations of thinking domains and the total score, as shown in **Table 2. Table 2** indicates the significance of the Pearson correlation coefficient for domains' scores, and the total score is high, indicating the internal consistency of the test.

**Table 1.** Test reliability of exploratory thinking domains.

| Domains | Observation | Interpretation | Experiment | Definition | Conclusion |
|---|---|---|---|---|---|
| Reliability Coefficient | 0.82 | 0.87 | 0.75 | 0.72 | 0.84 |
| Significance | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Domains | Using numbers | Classification | Hypotheses | Impact of variables | Total |
| Reliability coefficient | 0.86 | 0.91 | 0.82 | 0.76 | 0.89 |
| Significance | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |

**Table 2.** Internal consistency of the exploratory thinking domains test.

| Domains | Observation | Interpretation | Experiment | Definition | Conclusion |
|---|---|---|---|---|---|
| Correlation coefficient | 0.83 | 0.90 | 0.92 | 0.91 | 0.92 |
| Significance | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Domains | Using numbers | Classification | Hypotheses | Impact of variables | |
| Correlation coefficient | 0.91 | 0.92 | 0.93 | 0.92 | |
| Significance | 0.01 | 0.01 | 0.01 | 0.01 | |

For testing time, the appropriate time for the test was calculated through the average time taken by each student, which was 45 minutes.

For the final form of the test, the test included a notebook for the test items, an instruction page, and a separate answer sheet. Then, the test was corrected. The exploratory thinking test consisted of 9 sub-domains, each of which had several items followed by four options. Accordingly, students select the correct option and receive one degree for the correct answer and zero for the wrong one. The total score of the test is 28 degrees (**Table 3**).

The first stage for field testing, preparing for the field test, includes:

(i) Fulfilling the requirements for teaching the "Unit of Energy," including printing the student's activity notebook and teacher's guide, and preparing the used materials and tools.
(ii) Meeting the experimental group science teacher and explaining the objectives and implementation of SEPs.
(iii) Creating a suitable classroom for experimental group students by providing a display screen and arranging seats to activate interaction.
(iv) Pre-testing exploratory thinking on the experimental and control group students in the second semester of 2019/2020.
(v) Verifying the equivalence between experimental and control groups by using a pre-test, correcting the answer sheets, and monitoring grades. A t-test was used to compare the mean scores of the two groups in the research tools, as shown in **Table 4**. **Table 4** illustrates no differences between the mean scores of control and experimental groups in all research variables, indicating a high degree of equivalence.

The second stage for field testing, carrying out the research experiment, includes: The "Unit of Energy" was taught to the experimental and control group students, using exploratory activities and traditional methods, respectively.

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The third stage for field testing, post-test, includes: After completing the unit's teaching for experimental and control groups in light of SEPs and the traditional method, the research tools were applied.

**Table 3.** Features of the exploratory thinking test.

| Domains | Items | No. of items |
|---|---|---|
| Observation | 21-22-24 | 3 |
| Interpretation | 1-8-13-15 | 4 |
| Conclusion | 5-16-18 | 3 |
| Experiment | 2-4-11 | 3 |
| Definition | 3-20-25 | 3 |
| Using numbers | 6-10 | 2 |
| Hypotheses | 7-17-19-23 | 4 |
| Impact of variables | 12-26- 27 | 3 |
| Total | 28 | |

**Table 4.** "T" value and significance level.

| Tool | Domains | Experimental group N=30 | | Control group N=30 | | "T" test | Significanc e |
|---|---|---|---|---|---|---|---|
| | | Arithmetic mean | Standard deviation | Arithmetic mean | Standard deviation | | |
| Exploratory thinking | Observation | 0.875 | 0.421 | 0.91 | 0.39 | 0.308 | Insignificant |
| | Interpretation | 0.75 | 0.43 | 0.84 | 0.36 | 0.924 | Insignificant |
| | Experiment | 0.87 | 0.49 | 0.96 | 0.40 | 0.836 | Insignificant |
| | Definition | 0.61 | 0.43 | 0.43 | 0.25 | 1.39 | Insignificant |
| | Conclusion | 0.81 | 0.39 | 0.87 | 0.33 | 0.68 | Insignificant |
| | Using numbers | 0.56 | 0.50 | 0.50 | 0.43 | 0.46 | Insignificant |
| | Classification | 1.12 | 0.60 | 1.15 | 0.72 | 0.18 | Insignificant |
| | Hypotheses | 1.09 | 0.39 | 1.06 | 0.35 | 0.34 | Insignificant |
| | Variables | 6.66 | 1.69 | 6.53 | 1.29 | 0.33 | Insignificant |
| | Total | 13.31 | 3.39 | 13.06 | 2.58 | 0.33 | Insignificant |

## 3. RESULTS AND DISCUSSION

To test the validity of the research hypothesis, the "T" test was used for the differences between the experimental and control groups in the post-test of exploratory thinking, as shown in **Table 5**. **Table 5** illustrates significant differences between the mean scores of the experimental and control groups in the exploratory thinking domains and total score. "T" value was at the significance level of 0.01, favoring the experimental group. To answer the second question, the effect size was calculated using Eta square, as shown in **Table 6**.

**Table 6** shows the high value of the Eta square, indicating the effectiveness of exploratory activities based on SEPs of NGSS at exploratory thinking and its various domains, except for the "using numbers" domain, which was moderate.

Research findings of the exploratory thinking test post-test indicated a high level of exploratory thinking for experimental group students who studied the activities of the "Unit of Energy" in the light of SEPs, unlike control group students who studied the same unit traditionally. Thus, the research findings are consistent with the results (Kuhn *et al*., 2017; Kang *et al*., 2018) that demonstrated the effectiveness of students' practice of SEPs based on

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NGSS in developing some variables and educational goals, in general, and thinking, in particular.

**Table 5.** Means, standard deviations, "T" value, and the significance level of the post-test of exploratory thinking.

| Domains | Experimental group | | Control group | | "T" value | Significance |
|---|---|---|---|---|---|---|
| | Arithmetic mean | Standard deviation | Arithmetic mean | Standard deviation | | |
| Observation | 2.91 | 0.29 | 1.65 | 0.48 | 12.48 | 0.01 |
| Interpretation | 3.78 | 0.55 | 1.25 | 0.62 | 17.21 | 0.01 |
| Experiment | 3.00 | 0.00 | 1.28 | 0.58 | 16.73 | 0.01 |
| Definition | 2.96 | 0.17 | 1.53 | 0.67 | 11.71 | 0.01 |
| Conclusion | 2.91 | 0.29 | 1.53 | 0.51 | 13.24 | 0.01 |
| Using numbers | 1.84 | 0.36 | 1.46 | 0.67 | 2.76 | 0.01 |
| Classification | 2.93 | 0.24 | 1.62 | 0.49 | 13.50 | 0.01 |
| Hypotheses | 3.91 | 0.29 | 1.37 | 0.55 | 22.81 | 0.01 |
| Impact of variables | 2.87 | 0.33 | 0.71 | 0.45 | 21.51 | 0.01 |
| Total | 27.12 | 1.00 | 12.43 | 2.66 | 29.17 | 0.01 |

**Table 6.** Effect size of using exploratory activities based on ESPs of NGSS on the exploratory thinking of the experimental group.

| Domains | T" value" | T2 | Freedom degree | Eta square | Significance |
|---|---|---|---|---|---|
| Observation | 12.48 | 155.75 | 62 | 0.71 | High |
| Interpretation | 17.21 | 296.18 | 62 | 0.82 | High |
| Experiment | 16.73 | 279.89 | 62 | 0.81 | High |
| Definition | 11.71 | 137.12 | 62 | 0.68 | High |
| Conclusion | 13.24 | 175.29 | 62 | 0.73 | High |
| Use number | 2.76 | 7.61 | 62 | 0.10 | Moderate |
| Classification | 13.50 | 182.25 | 62 | 0.74 | High |
| Hypotheses | 22.81 | 520.29 | 62 | 0.89 | High |
| Impact of variables | 21.51 | 462.68 | 62 | 0.88 | High |
| Total | 29.17 | 850.88 | 62 | 0.93 | High |

This study came up with a set of recommendations to employ SEPs in the educational process. For example, teacher preparation programs at the Colleges of Education should focus on preparing pre-service teachers in light of the NGSS and integrating them into teaching practices. Moreover, training programs are important for science teachers to identify the goals of NGSS and develop SEPs in the classrooms.

## 4. CONCLUSION

The present research paper demonstrated the effectiveness of exploratory activities based on SEPs of NGSS in developing exploratory thinking. Therefore, it is important to pay attention to NGSS, which represents the applied aspect of these standards and describes scientists' behaviors to engage in research and build models and theories about the natural world. Furthermore, exploratory activities based on SEPs enhance exploratory thinking among students.

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## 6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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