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The effectiveness of using the model-based thinking strategy in developing first-grade high school students' physical concepts and inquiry thinking skills

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Abstract

This research aimed to verify the effectiveness of using the model-based thinking strategy in developing first-grade high school students' physical concepts and inquiry thinking skills. To achieve this goal, the research used the experimental approach with a quasi- experimental design for the experimental and control groups. The sample of the study consisted of 67 students in the first grade of high school, and it was divided into two groups: the experimental group 33 students (who studied using the model-based thinking strategy) and the control group 34 students (who studied conventionally). The study used the following tools: the physical concepts test and the inquiry thinking skills test. The results of the current research revealed that there are statistically significant differences between mean scores obtained by the experimental and control groups in the physical concepts test as a whole and its different levels of knowledge favoring the experimental group, and there are statistically significant differences between mean scores obtained by the experimental and control groups in the inquiry thinking test as a whole and its different skills favoring the experimental group, and there is a positive statistically significant relationship between the development of physical concepts and inquiry thinking skills among the students of the experimental group. Finally, the research presented some recommendations and proposals, including conducting more studies on model-based thinking strategy, inquiry thinking skills, and physical concepts in various disciplines and age stages.

Keywords: model-based thinking strategy, mental models, physical concepts, inquiry thinking skills

INTRODUCTION

Recently, efforts to reform science, technology, engineering and mathematics (STEM) education have focused on scientific practices related to modeling and model-based thinking. Where the learner responds actively to the model and to the model-based learning (Hubbs et al., 2017). Scientific models are the basis for the scientific interpretation and prediction of scientific phenomena, and they work to transform the abstract aspects of scientific theories into a tangible reality that can be clearly understood and interpreted (Gilbert & Gusti, 2016).

Scientific ideas derive their strength from the scientific models that support them; these ideas are always changed as a result of the researchers and scientists' efforts in creating and revising scientific models. They are also used to support arguments and discussions about the nature of physical reality. Model-based thinking is an integral part of constructing and discussing scientific models, generating scientific ideas, and formulating interpretations around them (Latour, 1999).

Next generation science standards (NGSS) aim to make science teaching more compatible with the scientific practice of science, to achieve this, they emphasize on models and model-based thinking through which models become a simplified representation of all the most complex phenomena and centralized aspects in STEM learning, models are used in

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Contribution to the literature

- It aimed to verify effectiveness of using model-based thinking strategy in developing first-grade high school students' physical concepts and inquiry thinking skills. It comes in response to modern global trends that call for need to activate teaching strategies that focus on learner and allow him to build conceptual knowledge within complex science systems, mental models about scientific phenomena, innovate questions that lead to thinking, practice scientific interpretation, and prediction of scientific phenomena.
- It highlights the importance of model-based thinking strategy in facilitating the learner's experience and moving them from the thinking of novices to the thinking of expert, moving the learner towards gaining experience, building mental representations of the physical phenomenon, explaining the reason for the behavior of the physical phenomenon, designing and implementing physical experiments, building the real scientific meaning and allowing for the learner to engage in real and practical practice of generating and evaluating scientific knowledge.
- It directs the attention of physics teachers to the importance of developing physics concepts that form the basis of physical knowledge and the learner's inquiry thinking skills (using meaningful questions, collecting and analyzing data, interpreting results using evidence, presenting, and evaluating results) improving learner's engagement in learning process, and promotes a deep understanding of physics.

the model-based thinking strategy to simulate the scientific phenomenon, and the learner, through the process of research and scientific investigation, reaches the knowledge and the main ideas that form a (knowledge base), conduct practical practices, construct comprehensive and interrelated concepts, This process of research aims to construct, use, develop and revise models (Bryce et al., 2016).

There are many studies that encourage using the model-based thinking strategy; Solimani (2013) indicated that the collaborative implementation of model-based thinking activities helps students in improving their knowledge understanding and application, and problem solving skills. It enhances their preparation for the scientific concepts associated with the model, as well as conceptual understanding. Ifenthaler and Seel (2013) confirmed that model-based thinking is an appropriate approach to understanding the foundations of inductive and deductive thinking based on the fact that models are tools for thought. Zwickl and Hu (2015) indicated that in model-based learning it is necessary to link prior conceptual knowledge with the ability to construct models. It recommended the necessity to use model-based reasoning in teaching physics, as it represents a strong opportunity for the learner to construct scientific meaning. Zangori et al. (2017) also indicated that model-based thinking plays a critical role in learning scientific concepts and understanding the connections between them and enhances the learner's strong understanding of the causal mechanisms associated with scientific phenomena, as well, Russ and Odden (2017) indicated that Model-based thinking promotes learner's evidence-based thinking, where the learner uses models to build evidence, then moves from the evidence to revise the models. According to Tobin et al. (2018), model-based thinking promotes the construction of mental representations of specific systems, "scientific phenomena", as well as practical practices, reviewing models and including new information within them, while Tazl et al. (2019) indicated that model-based thinking enhances the learner's discussions and communication processes and improves his experience during speaking, Aikens (2020) indicated model-based thinking provides the learner with opportunities to engage in real investigative experiences, while the study of Bolger et al. (2021) indicated that it stimulates innovative and scientific thinking, investigation and idea generation .

The physical concepts are the basis on which the physics curricula are based in its different stages, as they represent the Infrastructure of knowledge, and they are considered a basic element of physics curricula. It is important to teach students physical concepts, as their development and usage in daily life are among the basic requirements for understanding organized scientific knowledge, its principles, laws, and theories that interpret many natural phenomena.

Helping the learner how to construct his conceptual knowledge within complex science systems is one of the goals of model-based thinking, and this is indicated by Luckie et al. (2011) that scientific concepts within science systems represent complex abstractions that experts use to analyze properties and explain qualities that are interrelated in the natural world and teaching them requires more than passively conveying large amounts of simple, real information.

Helping the learner understand scientific concepts and employing them in his daily life, and acquiring inquiry thinking skills, is one of the basic goals that science education seeks to achieve in the various academic stages. Many studies have reported that inquiry thinking views students as future scientists. Therefore, one of the main roles of educators is to teach students inquiry thinking skills and methods. Scientifically speaking, model-based thinking is a teaching strategy that incorporates inquiry thinking skills and extended thinking processes (Windschitl et al., 2008).

Through model-based thinking, the student learns inquiry skills, develops his questions, collects and interprets data, discusses conclusions, and criticizes different interpretations of the data. According to Lehrer and Schauble (2004), in model-based thinking, the learner participates in developing inquiry questions, determining how to measure variables, developing the data presentation process to represent the results well, constructing mental representations and using these representations in discussing the results, providing a framework for analyzing scientific phenomena, and using it as a tool in order for the learner to develop a more complex understanding about the phenomenon and allow him to reflect and apply his scientific experiences.

Bryce et al. (2016) asserted that model-based thinking has become one of the best educational practices in order for the learner to develop and modify models that express the phenomenon and simulate the original model of the universe in an inquiry context practiced by the learner using inquiry-thinking skills. The model-based learning strategy aims to prepare the learner to design, construct, and form mental models in order to develop his understanding of the natural or physical world.

It also aims to provide him with the opportunity to use models as a basis for exploring scientific phenomena, verifying the relationships that form the model, constructing different mental representations, and the interaction between these representations that express the system (Lee et al., 2012; Penner et al., 1998).

Therefore, the model-based thinking strategy is effective for constructing a deep understanding of scientific principles, laws and theories. It provides the learner with scientific practices that are exactly similar to what scientists practice when they ask questions, talk and write, discuss and construct models, and carry out scientific investigations to reach a more accurate understanding of natural phenomena theoretically and practically (White, 1993).

The current study seeks to know the effectiveness of the model-based thinking strategy in developing first-year high school students' physical concepts and inquiry thinking skills.

Research Problem

Physics is one of the basic and applied sciences, this development contributed to form a clear scientific curriculum, as it is one of the important academic subjects that are related to student's life and his community. It plays a vital role in understanding the world and is a condition for survival in the current rapidly changing technology world (Baran, 2016). Teaching physics is not only the transfer of knowledge to the student, but it contributes to the mental, skillful, emotional and social construction. Despite the modern trends in education that ensure the student's role in the educational process, the teaching process still makes the student passive, His role is limited to listening, and the reason for this is that teachers follow methods and techniques that do not help the student to acquire physical concepts correctly and do not help him practice thinking skills.

Many studies have shown that physical concepts are complex and difficult to teach and learn, and that the lack of a correct understanding of them will decrease the learner's performance in physics. The researchers emphasized that most physical concepts are difficult and neither the learner nor the teacher does not have the ability to deeply understand them (Nkwo et al., 2008). Despite the vital role that physics plays in technological progress, research has shown that the learner finds it very difficult to understand physical concepts such as thermal energy and waves, light waves and their applications, sound waves and their applications, vectors and balanced forces, gas laws, wave motion, simple harmonic motion, and projectile motion, and the laws of thermodynamics (Bello et al., 2018; Gurcay & Gulbas, 2017; Obafemi & Onwioduokit, 2013; Onwioduokit, 1996; Sokrat et al., 2014).

The researchers believe that the difficulties in learning and understanding physical concepts are a global problem. Many physical concepts represent a global difficulty for all students in any society, and students lack a deep understanding of process-oriented physical concepts such as voltage, current, force, friction, and tensile (Streveler et al., 2006). These difficulties include what is related to textbooks and the way they deal with concepts, and some of them are related to the methodology in which physical concepts are taught. Some of them are related to the nature of the physical concepts themselves, and some of them are related to the lack of the previous physical concepts in the knowledge structure of the learner. In addition, the learner stores and remembers physical concepts in general without applying them in new situations and dealing with them superficially without paying attention to addressing them at a deep level of understanding, which makes it difficult to learn and understand them well (Sokrat et al., 2014).

Accordingly, Aina (2013) indicated that the student often considers physics as a very difficult scientific subject of an abstract nature and that his performance in physics is not encouraging and his achievement is low. Therefore, it is necessary to pay attention to the use of teaching models and strategies that enhance the understanding of physical concepts so that the difficulties that prevent their learning can be removed.

In addition, students have difficulties in practicing inquiry thinking skills, such as the skill of scientific interpretation of scientific phenomena and their construction (Driver et al., 1985), therefore Wu and Hsieh (2006) indicated the importance of developing the skill of interpretation and its sub-skills such as identifying causal relationships skill, describing the thinking process, using data as evidence, and evaluating the learner's interpretations.

Lati et al. (2012) indicated a decrease in the level of practicing inquiry thinking skills, and attributed this to the lack of sufficient experience in practicing inquiry activities, Hammann et al. (2008) also indicated that students lack the basic competencies to practice scientific inquiry processes and skills, such as: planning experiments in an orderly manner, controlling variables, and controlling experiment.

Moller et al. (2010) added that more than 70% of students do not have basic inquiry thinking skills, such as formulating questions, generating hypotheses, planning a survey, and interpreting data. Williams et al. (2007) indicated that the teacher rarely uses the skills of scientific inquiry in his teaching, therefore the teacher's failure to use these skills affects the students' learning and practice of them.

Thus, it has become important to shift from acquiring knowledge to practicing inquiry thinking skills that enhance the application of this knowledge and develop students' understanding of the scientific aspects of the world (Harlen, 2014; Harrison, 2014; Familari et al., 2013).

Research Questions

This study seeks to answer the following main questions:

1. What is the effectiveness of using model-based thinking strategy in developing first-grade high school students' physical concepts ?
2. What is the effectiveness of using model-based thinking strategy in developing first-grade high school students' inquiry thinking skills?
3. What is the correlation between physical concepts and inquiry thinking skills in physics learning among first-grade high school students?

Research Hypotheses

The current study sought to verify the validity of the following hypotheses:

1. There are no statistically significant differences at the significance level 0.05 between the mean scores of the students in the two groups: experimental and control in the physical concepts test.
2. There are no statistically significant differences at the significance level 0.05 between the mean scores of the students in the two groups: experimental and control in the test of inquiry thinking skills.
3. There is a positive correlation between the scores of the experimental group students in the physical concepts test, and their scores in the inquiry thinking skills test in physics.

Importance of the Research

This research is important because it comes as a response to modern global trends that call for the necessity of activating teaching strategies that focus on the learner, allow him to build scientific knowledge, promote the construction of mental models about scientific phenomena, build conceptual knowledge within complex science systems, negotiate and discuss in science classes, build arguments and create questions that lead to thinking, as well as practice scientific interpretation and prediction of the scientific phenomena, and transform the abstract aspects of scientific theories into a tangible reality that can be clearly understood and interpreted.

Also, theoretical rooting of the model-based thinking strategy; clarifying its role in developing both physical concepts and investigative thinking skills and training the learner to practice inquiry thinking skills by solving scientific activities that enhance model-based thinking. It also directs the attention of physics teachers to develop learners' inquiry thinking skills, because of its importance in developing scientific knowledge and ideas and forming an understanding. In addition, providing physics teachers with an appropriate strategy for presenting physics content that contributes to develop physical concepts and inquiry thinking skills among high school students.

Research Limits

1. Objective limits: Force in two dimension unit from the first-year high school students' physics book.
2. Time limits: The research was conducted in the first semester of the academic year 2020-2021.
3. Place limits: The research was conducted in Dammam, Kingdom of Saudi Arabia.
4. Human limits: The current research was limited to a targeted group of first-year high school students in a government school in Dammam.
5. Tools limits: The study tools were limited to the application of the physical concepts test at the cognitive levels of recall, comprehension, application, analysis, synthesis, and evaluation. Inquiry thinking skills test represented in the use of meaningful questions, data collection and analysis, interpretation of results using evidence, presentation and evaluation of results.

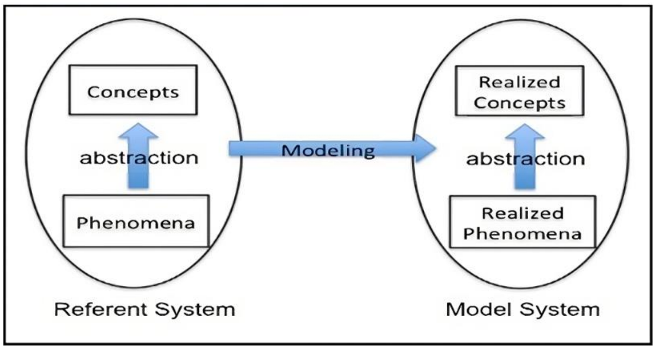

Figure 1. Modeling processes that occur in model-based thinking (Nowack & Casperson, 2014)

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

First Axis: Model-Based Thinking Strategy in Physics Teaching

Scientific practice showed great diversity in the methods that the scientists use in producing physical knowledge, and in constructing, improving, and purifying models from the world. Scientific ideas derive their strength from the models that support them, and scientific theories are always changing as a result of the scientists' efforts to create and revise scientific models (Lehrer & Schauble, 2006; Petrosino et al., 2003).

National efforts to reform education in science, technology, engineering, and mathematics focus on scientific practices, such as model-based thinking, where the learner responds actively to the model-based thinking and to the model-based learning (Hubbs et al., 2017). Scientifically, model-based thinking is a teaching strategy that contains extended thought processes (Windschitl et al., 2008). It plays a role in developing a deep understanding of science and mathematics by using a model that expresses a system or is similar to a cosmic phenomenon (Lethrer & Schauble, 2000).

Mental models are a part of all human endeavors towards understanding scientific phenomena because the individual is always constructing, forming, sharing, changing, developing and using these models in his private and practical life, they use them to understand themselves and the world around them. Model-based thinking mainly uses models to make the learner analyze and understand scientific and cosmic phenomena emphasizing the basic characteristics of scientific phenomena and concepts they study (reducing complexity) and enabling them to experience multiple perceptions (sometimes contradictory) of the same phenomenon (Nowack & Casperson, 2014).

Increasingly, model-based reasoning enhances learner's ability to construct scientific models to interpret observed phenomena (i.e., model of atom or magnetic field). Since scientific model is an idea or a group of ideas explain what causes a specific phenomenon in nature or makes phenomenon occur in this way, in order for learner to understand content deeply.

Definition of Model-Based Thinking Strategy

Model-based thinking is defined as a mental process that aims to develop mental representations that make phenomena accessible, visualizable, and transportable (Miller, 2015). Nowack and Casperson (2014) confirm model-based thinking as a style of thinking that uses modeling to identify the relationship between the reference system and the model system, as shown in **Figure 1**.

The reference system is a part of the world (real or imaginary) that is chosen for thinking and reflection as a system from a specific perspective. It contains phenomena, concepts and abstractions. The model system represents representations of perceived phenomena, concepts, and abstractions. The reference system is called the field model, while the model system consists of things and is called the objective model.

Modeling is the activity of constructing a model system based on a reference system. The processes of concept formation and abstraction are occurred and are activated during this activity. This represents the heart of model-based thinking, which aims to train the learner to identify scientific phenomena and concepts and link them through the conceptual formation processes represented in classification, assembly, disassembly, generalization, identification, and finding correct representations.

Thus, the model-based thinking strategy is defined as the strategy in which scientists use models to represent their imagination and perception about scientific phenomena, develop discussions, evidence and arguments, and defend or refute ideas in their peer community. Hence, it represents an entry point that allows the education of science negotiation pedagogy about the phenomena or the scientific model (Chen et al., 2016).

According to Ryan (2013) and Schorr and Clark-Koellner (2003), model-based thinking is a strategy in which the learner interprets a situation by placing it in an internal model that he owns, which helps him understand the situation, once the situation is determined within his mental model, transformations, modifications, additions or revisions can occur in the structure of this model. This personal mental model helps in building predictions, descriptions, or interpretations to be used in the problem. The process by which phenomena are understood using models is referred to as model-based thinking.

Luckie et al. (2011) also defines model-based thinking as the strategy in which the learner uses mental models as a method of scientific thinking and the representation of phenomena in science. These models focus on depicting and describing conceptual systems to help interpret current understanding and determine hypotheses. Models are the main mechanism by which science produces its interpretations and predictions.

Model-Based Thinking Strategy Steps

According to Fretz et al. (2002), model-based thinking usually consists of five steps:

1. Observation and data collection about the scientific phenomena, which motivates scientists to construct models that represent events and determine interactions and relationships between them.
2. Constructing a preliminary model about the phenomenon.
3. Application in which students engage in inquiry activities and apply a variety of scientific practices of value in science education, such as identifying questions, generating interpretations, and using justifications.
4. Evaluation and finding errors in the model in which further observations and revision of the model are made.
5. Revision of the preliminary model and entering into a cycle of correction and improvement; directing the learner to make connections between the aspects (variables) of the model and reviewing the appropriateness of the relationships between these aspects (variables).

Zwickl and Hu (2015) also identify the components of a model-based thinking strategy in defining the physical system, defining measurement tools, construction, prediction, interpretation of data, making measurement tools, comparison, limitation, revision, and troubleshooting. According to Dounas-Frazer et al. (2016), the model-based thinking strategy goes through many stages; the model construction (physical system) stage, defining the procedural definitions of the principles and concepts included in the model, and predictions construction about knowledge expected to be extracted from the model, comparison; where the learner compares the model he constructs with the original model and makes judgments about what he observes or deduces, suggesting proposal; that make the model fit and explain the phenomenon, the revision (physical system); where the learner troubleshooting in the model that expresses the phenomenon, and repairs and evaluates the model to accurately reflect the physical phenomenon.

Chen et al. (2016) indicate that the model-based thinking strategy uses mental models to support the practice of argumentation and discussion in science classes through six stages of performance: create a driving question, construct a tentative model in groups, construct a tentative argument in groups, negotiation models and arguments in a whole class discussion, then revise models and arguments through negotiation consult the experts, and reflect through writing.

While Gaytan (2017) identifies the components of model-based thinking strategy in introducing the scientific phenomenon, which requires students to create new knowledge based on the given information. Identifying patterns or phenomena, generating oridentifying questions about phenomena, investigating phenomena using a set of data and information, and practicing analysis and interpretation of this data and information as means of understanding. Generating a model that answers the question about the phenomena.

From the above; it is clear that many researchers agree that model-based thinking strategy consists of six main stages: presenting the scientific phenomenon, generating questions about the scientific phenomenon, investigating the scientific phenomenon and constructing the preliminary form of the model, revising the preliminary model, modifying the model related to the scientific phenomenon, and thinking or reflecting on the model (Dounas-Frazer et al., 2016; Gaytan, 2017; Lethrer & Schauble, 2000; Nowack & Casperson, 2014; Russ & Odden, 2017; Ryan, 2013; Shlezinger et al., 2021; Zwickl & Hu, 2015). These stages will be dealt in detail, as follows.

The first stage: Presentation of the scientific phenomenon

The scientific phenomenon is presented to students to observe, the learner begins to organize what he knows, and what he wants to know through the existing ideas included in the phenomenon, here the patterns or phenomenon are identified by presenting data related to the phenomenon.

The second stage: Generating/identifying questions about the scientific phenomenon

In this stage, the teacher asks motivational questions that lead the students to investigate the scientific phenomenon and construct ideas around it. The students also begin to ask questions about the phenomenon and determine what they notice about it.

The third stage: Investigating phenomena and construction of a preliminary model

In this stage, the teacher provides his students with a set of data, information, and ideas related to the questions raised, and asks them to generate ideas related to these questions, investigate the scientific phenomenon, generate the model that answers the questions related to the phenomenon, and linking previous conceptual knowledge to the mental model that is being formed. At this stage, the learner uses a set of ideas about the scientific phenomenon and his previous knowledge to construct a "preliminary model" about the phenomenon, which is a temporary model that simulates the scientific phenomenon, generates testable hypotheses, and constructs temporary arguments and evidence related to it to the proposed model to clarify the relationships or events within it. This stage is known as the model construction “physical system” stage.

The fourth stage: Revision of the preliminary model

In this stage, the preliminary models are reviewed and revised by conducting discussions and negotiations about models, consulting the expert (the teacher for example), revealing new ideas through research, criticizing scientific ideas and testing them, generating testable hypotheses, generating and evaluating scientific knowledge, and troubleshooting in the model.

The fifth stage: Modifying the model associated with the scientific phenomenon

The learner modifies the preliminary model of the phenomenon and constructs a scientific model that accurately expresses it, and the model takes one of the following patterns: concrete models, conceptual models, physical models, representational models, syntactic models, or hypothetical-deductive models. Here, the teacher asks his students to explain how the modified model expresses the scientific phenomenon or represents a system, and the extent to which it can highlight the relationships that are theoretically important in the scientific phenomenon; it is a model that is similar to the cosmic phenomenon and highlights the relationship between its aspects, and to experiment and apply the modified model in new situations.

The sixth stage: Thinking “reflection” about the model

The students construct inquiry questions about the scientific phenomenon that the model represents, determine how to measure variables, construct mental representations and use these representations in discussing this phenomenon, reflect on their experiences, apply their scientific understanding, identify the most important scientific ideas presented by the model, engage in an active thinking process about this model, construct meaning, and expand their use of the model in order to reach a deep understanding, and construct and develop scientific interpretations related to the scientific phenomena, and construct predictions expected to be extracted from the model, and compare between the model they built and the original model, and practice the model-based inquiry to reach accurate interpretations of the scientific phenomenon aspects.

Objectives of Model-Based Thinking Strategy

1. Facilitating the students’ experience and moving them from the thinking of novices to the thinking of experts, as the development of expertise takes place by building a deep foundation for real or factual knowledge, forming an organized and developed conceptual framework, and organizing and strengthening the retrieval process; It has a great influence on moving the learner towards experience compared to traditional learning or fact-based learning (Ryan, 2013).
2. Helping the learner to construct and modify models that express the phenomenon, which simulate the original model of the universe, in an investigative context practiced by the learner. It also plays a critical role in model literacy for the next generation of scientists, engineers, and problem solvers (Bryce et al., 2016).
3. Helping the learner to use models during the thinking process, revise and review these models, help him predict and interpret data, construct conceptual understanding, design and implement physical experiments, and construct real scientific meaning (Zwickl & Hu, 2015).
4. Helping the learner to construct, use and develop mental models, provide them with non-verbal ways “mental representations” to express understanding, and give them practice and confidence in talking about how the models interpret scientific observations (Bryce et al., 2016; Lee et al., 2012).
5. Enhancing the learner’s ability to predict and explain the behavior of the phenomenon using qualitative representations, explaining the reason for the behavior of the phenomenon, and promoting modeling practices that enable the learner to participate in science by creating, reviewing and revising models of the natural world (Miller, 2015).
6. Promoting the development of students’ thinking and reasoning skills, learning the cognitive structure of science, promoting scientific thinking about everything that is conceived in physics, viewing evidence-based thinking and model-based thinking as scientific thinking that establishes the construction of meaning about physical phenomena and the construction of evidence (Russ & Odden, 2017).
7. Allowing the learner to engage in a real, practical practice of generating and evaluating scientific knowledge. This practice aims to get the learner involved in model-based thinking as an essential means of learning and understanding science (Gouvea & Passmore, 2017; Passmore et al., 2014).
8. Providing the learner with the opportunity to troubleshoot the mental models that he creates, by practicing a non-linear and iterative process of construction, testing, revision and improvement, and this is what makes the researchers always emphasize that the process of constructing the model and troubleshooting is a basic theme in

model-based thinking (Dounas-Frazer et al., 2016).

9. Promote the practice of three types of model-based thinking, namely: first, analogical modeling, where the model represents what is common among members of the system in a specific context or problem. Second, visual modeling in which the external visual representations give the learner support for the construction and inference processes of the mental model, and these representations can model the phenomenon in different ways, including providing ideal representations of the aspects of the phenomenon and embodying the theoretical aspects of the models. Third, thought experimenting is a specific form of model-based thinking that builds clear goals in which possible real-world situations are represented (Nersessian & Patton, 2009).
10. Enhancing student engagement in the learning situation, stimulating the process of asking questions about the phenomenon, and encouraging the learner to think critically; dealing with data positively "struggles with data", giving enough time to practice thinking about the phenomenon and building a mental model that expresses and interprets the scientific phenomenon (Gaytan, 2017).

Many studies have focused on the importance of the model-based thinking strategy, including Solimani (2013), which indicated that implementing model-based thinking activities collaboratively can help students improve understanding of knowledge, apply problem-solving skills, and enhance conceptual understanding. Ifenthaler and Seel (2013) indicated that research in the mental models gives good examples of model-based thinking by applying thought-experiments and constructing analogy models that aim to interpret a new, unknown domain with reference to another known or specific domain.

Zwickl and Hu (2015) showed that model-based thinking supports construction, prediction, interpretation of data, identification of model limitations, and revision, employs the modeling process as a means of understanding, design and implement physical experiments, link prior conceptual knowledge with the ability to construct models, and construct real and attractive scientific meaning. Russ and Odden (2017) also indicated that the overlap between evidence-based thinking and model-based thinking enhances the construction of meaning in "physics" when studying a specific learning field such as electrostatics. Zangori et al. (2017) indicated the importance of including modeling practices and model-based thinking in curricula based on socio-scientific issues to support students' deep understanding.

Second Axis: Physical Concepts

Physical concepts and conceptual structure formation

Tolba (2007) points out that physics should be viewed as a content consisting of concepts, relationships, generalizations, laws and theories that are organized together in the form of a network of scientific relationships and connections based on physical knowledge of a special qualitative nature, which contributes to achieve a deep understanding of physical concepts. Concepts are defined as a set of generalizations, incidents, or special symbols that are grouped together on the basis of their common characteristics, which distinguish them from other groups and classes (Colgrove, 2012).

Concepts are packages of meaning, and they capture the regularity, patterns, or relationships between things, events, and other concepts (Novak, 1996). Every concept is a human invention, and a way to organize the world. Concepts are formed through an intellectual process in which mental functions such as memory, attention and reasoning participate language as a guide, and the cognitive structure is the basis on which the learner depends in constructing new knowledge, and in the occurrence of meaningful learning of scientific concepts (Cakir, 2008).

"Physical concepts" are the cognitive construction units of science, other units are formed from it such as generalizations, principles, laws and theories, it is the factor responsible for the occurrence of effective learning. By acquiring meanings and connotations, connections form between them to form a conceptual network, or what is known as the conceptual structure.

Tolba (2013) believes that the conceptual structure, according to Ausubel's perspective, plays an important role in learning new concepts, its learning is useful, and it is preserved that it can be linked with prior concepts and ideas that form the learner's conceptual structure, which are considered as Ideational Anchors on which learning of new concepts is based.

Cakir (2008) also believes that the individual's conceptual structure plays a necessary role in solving problems, as there is a strong correlation between the concepts in the learner's conceptual structure and the learning site that requires him to solve problems, and it also gives him more new ideas for further research or exploration and finding fruitful interpretations about the scientific phenomena.

Developing physical concepts as one of the physics education objectives

Forming and developing physical concepts is one of the objectives of teaching physics, and learning physical concepts does not based only on the learner's ability to remember them; rather, he should be able to apply them in new situations, and then it becomes necessary to adopt strategies and teaching models that support the concepts teaching in a procedural form in the field of learning and teaching physics.

Darmaji et al. (2018) emphasized that providing learners with scientific concepts contributes to giving them meaningful educational experiences, because it helps in achieving a high level of thinking, and thus provides them with the necessary skills to solve different problems by processing information, formulating conclusions and different solutions to the problem. Accordingly, Alves (2014) formulated the concept of conceptual thinking, which refers to the operation of mental processes related to the learner's attention towards the relationships between objects, events, or examples, and scientific phenomena. Also, in concepts-based thinking, the individual learns to distinguish and abstract the common characteristics that are formulated in a phrase that expresses the verbal significance of the concept in order to form generalizations, and to distinguish between elements or characteristics related to the concept and those that are not related to it.

Thus, in the future, with the learner's acquisition of scientific concepts; they become equipped with basic life skills, ways to protect themselves and others, and are able to deal with increasingly global problems and possess higher-order thinking skills (Eshach & Fried, 2005). Based on the foregoing, forming and developing learners' scientific concepts is one of the goals, objectives, and desired outcomes in the science curricula and their teaching in the different stages of education, especially physics. This requires applying and using strategies, models and teaching methods that enhance the construction and formation of physical concepts and their retention in order to use them in the different aspects of life (Ross & Willson, 2012).

Many studies focused on the importance of developing physical concepts, including Kumar and Mathur (2013), which indicated the effectiveness of using the concept acquisition model on developing, acquiring and understanding physical concepts, Falode and Gambari (2017) that referred to the development of physical concepts by applying (educational package) a series of laboratory and practical procedures for high school students, as it enables students to conduct physical experiments that require physical or high level technical skills and enhances their learning and understanding. Sobremisana (2017) indicated that the use of innovative physics devices generally led to an improvement in understanding of physical concepts and increased the level of motivation and confidence in students' learning. Rajibussalim et al. (2018) also indicated the effectiveness of inquiry science learning environments based on a STEM model with its fields (science, technology, engineering, and mathematics) to enhance students' understanding of physical concepts related to harmonic motion using a simple pendulum.

Third Axis: Inquiry Thinking Skills

Inquiry is a permanent and central term in the pedagogy language in the United States and other developed countries. During the second half of the twentieth century, "good science teaching and student learning" became increasingly associated with the term "inquiry" (Anderson, 2002; National Research Council [NRC], 2000). Scientific inquiry will always be the focus of science study. It is strongly emphasized by the United States science education documents such as the benchmarks for scientific literacy (American Association for the Advancement of Science [AAAS], 1993), national science education standards (National Research Council [NRC], 1996), NGSS Lead States (2013), England national science curriculum (2015), and Australian science curriculum (2015); all of these countries have included scientific inquiry as one of their goals to help students develop their understanding of the nature of science, its methods and processes, and to answer scientific questions (Lee & Shea, 2016).

Practicing inquiry is one of the important approaches to scientific education (Abd-El-Khalick et al., 2004) because it contributes to learning scientific concepts easily and in depth, increasing understanding of the nature of science, developing meaningful understanding and building scientific interpretations through the exploration of natural phenomena, and practicing scientific thinking. It is defined as the diverse ways in which scientists study the natural world, suggesting evidence-based interpretation, and it refers to the learner's activities in which scientific knowledge and ideas are developed (NRC, 2000).

Harrison (2014) confirms that one of the characteristics of inquiry learning is that the learner practices a set of mental skills known as inquiry skills such as making observations, collecting data, analyzing and synthesizing information, and setting results in order to develop problem-solving skills. Hasse et al. (2014) also confirms that science educators agreed that scientific inquiry is essential for acquiring and developing scientific knowledge, understanding scientific ideas, knowing the factors responsible for the phenomenon, and knowing the control-of-variable-strategy.

Inquiry Thinking Skills

Inquiry thinking is defined as a set of interrelated processes through which scientists and students ask their questions about the world and natural phenomena, and when performing this, both the scientist and the learner acquire knowledge and develop a deep understanding of concepts, principles, models and theories (Lee & Shea, 2016). It is also defined as a set of skills used by the learner while dealing with a complex situation, and in understanding and learning scientific and mathematical knowledge, and is represented in the skill of analyzing and interpreting data from tables and graphs, and identifying, understanding and using relationships between variables (Wu & Hsieh, 2006). It is a set of mental skills that the learner uses when trying to investigate a phenomenon, and when trying to construct scientific interpretations (Kuhn et al., 2000; Shimoda et al., 2002). According to Moller et al. (2010), scientific inquiry can be distinguished into four basic skills: formulating questions, generating hypotheses, investigation planning, and interpreting data.

Inquiry thinking skills are determined in the context of scientific research as formulating research questions, generating hypotheses, identifying and controlling variables, designing an experiment, observing and measuring, using simple measurement tools, recording, organizing, analyzing and interpreting data, evaluating results, and linking observations to scientific theories (Kruit et al., 2018; Osborne, 2015). Inquiry thinking skills are known as science process skills, and they reflect the behavior of scientists, and are classified into basic scientific inquiry skills such as observation, deduction, interpretation, and asking questions, and integrated scientific Inquiry skills such as generating hypotheses, controlling variables, and experimenting (Dudu & Vhurumuku, 2012; Kazeni et al., 2018).

Inquiry thinking skills are determined in identifying the questions and concepts that guide, design, and conduct empirical investigations using appropriate tools, collecting evidence through observation and using sources of information, analyzing, formulating interpretations, constructing and revising scientific models with the use of logic and evidence, and investigating those interpretations and models (Barrow, 2006; Harlen, 2014).

Developing Inquiry Thinking Skills

Research has shown that teaching science through inquiry plays a strong role in enabling students to acquire knowledge and cognitive skills and increases interest and positive attitude towards science (Kask & Rannikmäe, 2006). According to Abrahams and Millar (2008), it is important to develop students' ability to understand Scientific concepts and the develop inquiry skills.

Learning science must include inquiry processes and skills so that the learner acquires a conceptual understanding of science and scientific skills. inquiry-based education is effective in enhancing students' science literacy skills and confidence, improving the learner's engagement in the learning process, developing academic achievement, achieving effective learning outcomes, promoting a deep understanding of the learning material, and developing scientific trends (Ertikanto et al., 2017; Tekin & Mustu 2021).

Sadeh and Zion (2009) believes that it is important for the learner to practice the process of designing a scientific inquiry through which he collects data on how the phenomenon occurs in the natural world using the senses and measurement tools that support the ability of the senses, controlling the variables related to the inquiry, generating hypotheses and testing their validity, predicting and interpreting results and linking what has been observed to what is known to him, which leads to form new knowledge and construct valuable ideas.

The importance of the inquiry thinking skills is determined in helping the learner to practice the scientific inquiry in order to solve problems, transfer scientific ideas and results and make the decision, and directing his attention to the scientific phenomena. It also enables him design and conduct scientific research to develop effective solutions for the problem, promote the link between aspects of scientific knowledge together, creativity, innovation, and the ability to solve everyday problems (Harlen, 2014).

A growth in students' inquiry thinking skills leads to enhance their cognitive abilities that are important for understanding the real world and forming practical attitudes (such as curiosity, interest, and objectivity) (Kask & Rannikmäe, 2006).

According to Klahr and Nigam (2004), Kruit et al., (2018), and Lazonder and Harmsen (2016), teaching and developing scientific inquiry skills using teaching strategies and models enhances the development of inquiry thinking skills such as the skill of controlling variables, asking questions, thinking about big ideas, testing them, interpreting things, noticing how things change, and using evidence to draw conclusions, making decisions, discovering knowledge, conducting and carrying out real tasks, and performing inquiry activities.

Pedaste et al. (2021) and Williams et al. (2007) state that scientific activities and teaching models based on mental activity and thinking are ideal for teaching students scientific inquiry skills, developing scientific argumentation skills, identifying problems and inquiry them, generating hypotheses, constructing models, collecting and analyzing data, identifying and interpreting results, as well, providing an opportunity to acquire knowledge about the scientific content.

Ješková et al. (2016) and Lee and Shea (2016) emphasize that the teacher should seek to develop inquiry thinking skills related to analysis, interpretation, and discussion or communication, data collection, experiment design and implementation by asking inquiry questions to his students in order to construct scientific knowledge and understanding scientific phenomena.

According to Ertikanto et al. (2017), the process of improving and developing students' inquiry skills is greatly influenced by the teacher's roles as a teacher as a guide and as a motivator for the learning process. The teacher who is efficient in managing inquiry science

Table 1. Number of students in experimental & control group

Group	Number of students registered at beginning of experiment	Number of students excluded from experiment	Number of students within statistical treatment
Experimental	36	3	33
Control	39	5	34
Total	75	8	67

classes greatly affects the academic performance of the learner, and it is necessary to select teaching strategies and models that enhance inquiry processes and skills when learning science. Wu (2013) indicated the effectiveness of transformative learning in developing students' independence and scientific inquiry skills in genetics. Mustafa and Trudel (2013) indicated the effectiveness of using two cognitive tools (interactive computer simulation and the use of physical objects) on developing high school students inquiry skills in physics laboratories. Wang et al. (2015) indicated the effectiveness of model-based inquiry in developing students' inquiry skills in the virtual physics laboratory, such as developing questions and procedures, conducting experiments, generating conclusions in an attempt to explore various phenomena and construct and reconstruct models based on the results achieved by scientific investigations. As Ješková et al. (2016) also indicated the effectiveness of inquiry-based learning in mathematics, physics, and informatics in developing students' inquiry thinking skills, such as data analysis and interpretation skills, and argumentation skills. Kazeni et al. (2018) indicated the effectiveness of individual and group inquiry in developing inquiry thinking skills in scientific research, such as graphing skills. Kruit et al. (2018) also indicated the effectiveness of using direct teaching on acquiring inquiry thinking skills when teaching science. Polyium et al. (2018) investigated the effectiveness of procedural work with different levels of inquiry in developing the special inquiry thinking skills required for the study of hydrocarbon compounds among university students in Thailand. While Beltrán (2018) showed the effectiveness of the problems- based learning strategy in developing inquiry thinking skills among second grade students, and Ozturk (2021) indicated that activities based on STEM help in developing scientific inquiry skills. Ješková et al. (2022) indicated that active learning represented in inquiry-based science education strategies is essential for developing students' inquiry knowledge and skills in the 21st century.

METHODOLOGY

Research Approach

To achieve the research objectives, the experimental approach, in its quasi-experimental design, was used, which is based on applying pre-/post-test design to two unequal groups, one experimental, which studied using the model-based thinking strategy, and the other control, which studied in the conventional method.

Research Sample

Al-Bassam (2015) defined the research sample as "a subset of vocabulary of population of the study in question, to be selected properly to represent the study population". The sample of this research comprised 67 students enrolled in **first-grade high school** stage in one public school in Dammam District. Experimental group comprised 33 students and control group comprised 34 students (**Table 1**). The sample was purposive, because this school was equipped with the devices and tools needed to conduct this research.

Research Variables

Independent variable

Using model-based thinking strategy.

Dependent variables

Physical concepts, second, inquiry thinking skills, which are using meaningful questions, data collection and analysis, interpret results, using evidence, presentation, and evaluation of results in physics.

Preparation of Experimental Processing Tools and Measurement for Research

The preparation of the experimental processing tools went through the following steps:

1. **Choosing** ***the educational content:*** The force in one dimension unit was chosen from the physics course for the first semester of the first year of high school, because it contains a large number of physical concepts, relations and abstract physical laws that help in forming the conceptual structure of students, namely: force and motion, Newton's first law, Newton's second law, uses of Newton's second law, contact forces and field forces and Newton's third law, forces of ropes and strings, and vertical force, in addition to the knowledge, activities, and tasks that are easily formulated according to model-based thinking strategy. There are also a number of activities and tasks that help in developing inquiry thinking skills, in addition to their relevance to students' real-life situations.
2. ***Analysis of the content of the selected unit:*** To determine the list of physical concepts included in the forces unit in one dimension in the physics course for the first semester of the first- grade high school of the academic year (2020-2021), and after

conducting the analysis process; the validity and reliability of this analysis were calculated, as follows:

a. *Analysis validity:* The list of physical concepts was presented to a panel of curricula and teaching methods of physics staff members, and some teachers of physics; To ensure the comprehensiveness of the analysis of the physical concepts contained in the unit of forces in one dimension, and the extent to which the verbal significance of the physical concepts in the unit is appropriate. They indicated the validity of the analysis in light of the unit of analysis (physical concepts), and they also indicated the comprehensiveness of the analysis of the physical concepts included in the unit.

b. *Analysis reliability:* The reliability was calculated through the consistency of the individuals, as the agreement between the results of the analysis reached by the researchers and two colleagues, using the Holsti (1968) equation and it was 0.97, which is a high value indicating of the analysis reliability.

3. ***Prepare the teacher's guide:*** The teacher's guide for the "forces in one dimension" unit chosen from the physics book was prepared using a model-based thinking strategy with the aim of developing high school students' physical concepts and inquiry thinking skills. The guide includes objectives of the guide, and scientific basis of model-based thinking strategy, an instruction to study variables (physical concepts and inquiry thinking skills), educational objectives, timeline of unit topics, and implementation of lessons in "forces in one dimension" unit using model-based strategy.
4. ***Presenting the guide to the jury members:*** The teacher's guide was presented to a group of jury members specialized in curricula and teaching methods of physics, and a group of physics teachers to ensure the content validity of the teacher's guide. They agreed upon the scientific and linguistic correctness, and some modifications were made in the light of their suggestions, then the guide was in its final form for application.

Research Tools

Physical concepts test

The test consisted of 46 multiple-choice questions. Force and motion seven questions, Newton's first law seven questions, Newton's second law 14 questions, uses of Newton's second law seven questions, contact forces and Newton's third law seven questions, forces of ropes and strings two questions, vertical force two questions, in the cognitive levels of recall, comprehension, application, analysis, synthesis and evaluation. To ensure the validity of the test, it was presented to a panel of curricula and methods of teaching physics staff members, teachers and supervisors of physics, to judge on the extent to which the items belong to the cognitive levels of the objectives, the appropriateness of the alternatives for each question in the test, the scientific validity and linguistic integrity, and the comprehensiveness of the questions to the educational content. Some modification have been done in the light of the jury members opinions. The total test score was 46. The test was applied to a pilot sample consisting of 70 students outside the research sample to calculate the reliability of the physical concepts achievement test by using the split half method, which was 0.77, this result was corrected using the Spearman-Brown equation to reach the reliability coefficient 0.83, which is a high and acceptable reliability coefficient. The internal consistency validity of the physical concepts achievement test was calculated to determine the correlation between the scores of each item of the test with the cognitive dimension to which it belongs, it was ranged between 0.253 and 0.704, and between each cognitive dimension of the test dimensions with the other dimensions and the total score of the test, which ranged between 0.370 and 0.881 using the Pearson correlation coefficient, which are statistically significant correlation coefficients at the level of significance 0.05 and 0.01, and this indicates that the test is internally consistent. The difficulty and ease coefficients for each item of the physical concepts achievement test ranged between 0.20 and 0.80. Questions that students answer correctly in the range from 20% to 80% are considered acceptable for the ease and the difficulty coefficients. The discrimination coefficients for each item of the physical concepts achievement test ranged between 25% and 70%, which are acceptable discrimination coefficients (Wendler & Walker, 2006). The appropriate time for applying the test was determined by calculating the average time taken by the first and last student to finish the answer, the appropriate time for the physical concepts test is 50 minutes.

Inquiry thinking skills test

The test is built based on reviewing some studies in the field of Inquiry thinking skills (Beltrán, 2018; Ertikanto et al., 2017; Ješková et al., 2016, 2022; Kazeni et al., 2018; Kruit et al., 2018; Lazonder & Harmsen, 2016; Ozturk, 2021; Polyium et al., 2018). The test consists of 26 multiple-choice questions. It was devoted to the skill of using meaningful questions (six questions), to the skill of collecting and analyzing data (six questions), to the skill of interpreting results using evidence (six questions), and to the skill of presenting and evaluating results

Table 2. Equivalence of experimental & control groups in physical concepts & its dimensions (recall, comprehension, application, analysis, synthesis, & evaluation)

Cognitive level	Group	n	Mean	SD	t-value	VS	Significance
Recall	Experimental	33	4.36	1.62	0.116	0.908	Not significant
	Control	34	4.41	1.78			
Comprehension	Experimental	33	2.76	1.28	0.075	0.941	Not significant
	Control	34	2.74	1.16			
Application	Experimental	33	2.36	1.37	0.226	0.822	Not significant
	Control	34	2.29	1.14			
Analysis	Experimental	33	2.21	1.02	0.740	0.462	Not significant
	Control	34	2.38	0.85			
Synthesis	Experimental	33	1.48	0.87	1.686	0.097	Not significant
	Control	34	1.21	0.41			
Evaluation	Experimental	33	1.36	0.65	1.117	0.268	Not significant
	Control	34	1.18	0.72			
Physical concepts test as a whole	Experimental	33	14.51	3.94	0.331	0.742	Not significant
	Control	34	14.21	3.72			

Note. SD: Standard deviation & VS: Value of significance

Table 3. Equivalence of experimental & control groups in variable of inquiry thinking skills (using meaningful questions, collecting & analyzing data, interpreting results using evidence, & presenting & evaluating results)

Cognitive level	Group	n	Mean	SD	t-value	VS	Significance
Using meaningful questions	Experimental	33	2.36	1.11	1.01	0.318	Not significant
	Control	34	2.12	0.88			
Collecting & analyzing data	Experimental	33	1.55	0.97	0.92	0.363	Not significant
	Control	34	1.76	0.99			
Interpreting results using evidence	Experimental	33	1.73	1.09	0.34	0.732	Not significant
	Control	34	1.82	1.19			
Presenting & evaluating results	Experimental	33	2.15	1.20	0.77	0.447	Not significant
	Control	34	1.94	1.04			
Inquiry thinking skills test as a whole	Experimental	33	7.79	2.08	0.27	0.790	Not significant
	Control	34	7.65	2.23			

Note. SD: Standard deviation & VS: Value of significance

(eight questions). To ensure the validity of the test, it was presented to a panel of curricula and methods of teaching physics staff members, teachers and supervisors of physics, to evaluate the extent to which questions belong to inquiry thinking skills, the appropriateness of alternatives for each question in the test, scientific correctness and linguistic integrity. the modifications were made in the light of the jury opinions. The total test score was 26. The test was applied to a pilot sample consisting of 70 students outside the research sample to calculate the reliability of the inquiry thinking skills test in physics by the split half method, and it was 0.70, and it was corrected using the Spearman-Brown equation to reach the stability coefficient 0.80, which is a high and acceptable reliability coefficient. The internal consistency validity of the Inquiry thinking skills test was calculated to determine the correlation between the scores of each item of the test and the skill to which it belongs from the dimensions of the test, which ranged between 0.30 and 0.627, and between each skill of the test with the other skills, and the total score of the test, which ranged between 0.335 and 0.844 using the Pearson correlation coefficient, which are statistically significant correlation coefficients at the significance level 0.05 and 0.01, and this indicates that the test is internally consistent. the average time for the actual performance of the test for applying the test was determined by calculating the time taken by the first and the last student to finish the test, then the appropriate time for inquiry thinking skills test is 45 minutes.

The pre-application of the study tools (equivalence of the two groups)

The physical concepts test and the inquiry thinking skills test were pre-applied to the two research groups to know the equivalence between the experimental and the control groups, and the t-test was used for independent samples to identify the differences between the experimental and the control groups before the real application of physical concepts test as a whole and its dimensions (recall, comprehension, application, analysis, synthesis, and evaluation), as shown in **Table 2**, and in the inquiry thinking skills test and its skills (using meaningful questions, collecting and analyzing data, interpreting results using evidence presenting and evaluating results), as shown in **Table 3**.

Table 4. Results of post-application of physical concepts test & its sub-dimensions

Cognitive level	Group	n	Mean	SD	t-value	η2	d-value	ES
Recall	Experimental	33	9.75	2.59	3.00	0.15	0.82	High
	Control	34	7.83	2.40				
Comprehension	Experimental	33	7.03	1.45	7.04	0.43	1.75	High
	Control	34	4.53	1.46				
Application	Experimental	33	7.27	2.43	5.01	0.28	1.25	High
	Control	34	4.59	1.94				
Analysis	Experimental	33	6.52	1.86	7.17	0.44	1.77	High
	Control	34	3.71	1.31				
Synthesis	Experimental	33	2.67	0.48	6.09	0.36	1.50	High
	Control	34	1.68	0.81				
Evaluation	Experimental	33	4.09	1.21	6.16	0.37	1.54	High
	Control	34	2.41	1.01				
Physical concepts test as a whole	Experimental	33	37.24	9.19	6.30	0.38	1.56	High
	Control	34	24.79	6.84				

Note. SD: Standard deviation; η2: Squared eta; & ES: Effect size

Table 2 and **Table 3** showed that there are no statistically significant differences between the mean scores obtained by the experimental and the control groups on pre-application of the two research tools (physical concepts test and inquiry thinking skills), which confirms the equivalence of the two groups.

RESEARCH RESULTS AND DISCUSSION

First Question

To verify the first hypothesis of the research, which states: "There are no statistically significant differences at the significance level 0.05 between the mean scores of the students in the two groups: experimental and control in the physical concepts test". The "T" value was calculated to compare the mean scores of the experimental and the control groups in the post-application of the physical concepts test as a whole and its sub-components, and the value of the effect size was calculated using the coefficient as shown in **Table 4**.

Table 4 indicates that there are statistically significant differences at 0.05≥α between the mean scores obtained by the experimental and the control groups in the physical concepts test as a whole and in its different cognitive levels favoring the experimental group (this indicates the rejection of the first null hypothesis) and accepting the alternative hypothesis, which stated that There is a statistically significant difference at the level 0.05≥α between the mean scores obtained by the experimental and the control groups in the post-application of the physical concepts test as a whole and its dimensions (recall, comprehension, application, analysis, synthesis, and evaluation) favoring the experimental group.

Table 4 shows that the effect size is greater than 0.8 for each level of the physical concepts test and the test as a whole. This indicates that the effect size of the experimental treatment (model-based thinking strategy) in developing physical concepts is high, and this can be due to the fact that the model-based thinking strategy is considered one of the strategies that support the teaching of physical concepts in a procedural way, and reinforce the constructivist perspective in learning physical concepts and the necessity to convert the educational process from focusing on teaching physical facts to teaching physical concepts and ideas, and achieving a deep understanding of physical concepts, their construction and development, and applying them in new situations. It also reinforces the concept of concept based thinking, which refers to the operation of the mental processes associated with the learner's attention towards the relationships between events or examples and physical phenomena, in addition, providing the learner with the ability to interpret the concept and think about the rules that govern its construction and formation (Alves, 2014).

This result agrees with the results of previous studies in the importance of using model-based thinking and mental models as a strategy for teaching physical concepts, constructing integrated and multiple representations for them, and enhancing thinking in concepts learning (Gaytan, 2017; Ifenthaler & Seel, 2013; Russ & Odden, 2017; Solimani, 2013; Zangori et al., 2017; Zwickl & Hu, 2015).

This result also supports what was indicated by the results of previous studies that it is important make the teaching process concentrate on constructing and forming physical concepts, improving students' understanding of them and helping them to construct physical concepts in a meaningful way, linking conceptual knowledge with life situations, and creating positive scientific habits and attitudes to encourage students to Learn physical concepts (Gurcay & Gulbas, 2017; Obafemi & Onwioduokit, 2013; Rajibussalim et al., 2018; Sobremisana, 2017; Sokrat et al., 2014; Sun et al., 2015).

This result can be attributed to the fact that the model-based thinking strategy encourages the learner to

Table 5. Results of post-application of inquiry thinking skills test & its sub-dimensions

Cognitive level	Group	n	Mean	SD	t-value	η2	d-value	ES
Using meaningful questions	Experimental	33	4.61	1.36	2.88	0.14	0.81	High
	Control	34	3.60	1.51				
Collecting & analyzing data	Experimental	33	4.73	0.98	3.50	0.16	0.87	High
	Control	34	3.68	1.43				
Interpreting results using evidence	Experimental	33	4.88	0.86	5.07	0.28	1.25	High
	Control	34	3.47	1.35				
Presenting & evaluating results	Experimental	33	6.58	1.15	7.92	0.49	1.97	High
	Control	34	4.15	1.35				
Inquiry thinking skills test as a whole	Experimental	33	20.76	3.60	6.34	0.38	1.56	High
	Control	34	14.85	4.00				

Note. SD: Standard deviation; η2: Squared eta; & ES: Effect size

use mental models that simulate scientific phenomena, and carrying out the scientific research and investigation in order to reach the main knowledge and ideas that form the conceptual knowledge base that needed to do a job or performance and conduct practical practices that enhance their interdependence in a meaningful way (Bryce et al., 2016). This result indicates that model-based thinking helped the learner to construct abstract conceptual knowledge and use it in analyzing and interpreting the characteristics and properties related to the natural world (Luckie et al., 2011), which helped to transfer large amounts of interrelated conceptual information to memory and store it in a strong form so that it can be easily recalled, deeply understand and apply it in new situations, analyze it to determine its critical characteristics, or used it to revise the initial mental model and reconstruct it again.

This results is supported by Gouvea and Passmore (2017) and Passmore et al. (2014), which indicated that the model-based thinking strategy allows the learner to engage in a real practical practice represented in generating and evaluating physical concepts and knowledge associated with them as a result of using mental modeling and representations of it, which represents a path to learning and understanding.

This result can be also interpreted in light that the model-based thinking strategy enhances the learner's research process and insistence on getting information, developing his conceptual understanding, directing his thoughts and questions towards constructing physical concepts correctly, and enhancing his ability to participate in controversy and discussions about the scientific model, phenomenon, and the physical concepts included in it (Gouvea & Passmore, 2017), which is reflected in the ability to remember, understand, apply, analyze, synthesize, and evaluate the learned physical concepts.

By extrapolating the stages of the model-based thinking strategy, it found that it enhances the learning of physical concepts. At the stage of presenting the scientific phenomenon, the learner reviews all the previously learned physical concepts that are related to the new physical concepts included in the phenomenon.

In the stage of investigating phenomena and construction of a preliminary model, the learner generates the physical concepts and ideas that form the preliminary model and links the previous conceptual knowledge to the mental model that he forms and uses visual models that link images and concepts together and clarify the relationships between the ideas that are understood. Finally, in the stage of thinking "reflection" about the model; the learner is given the opportunity to reflect on his experiences, apply his understanding of physical concepts in new situations, engage in an active thinking process about the physical concepts presented by the mental model, and construct and develop scientific interpretations related to scientific phenomena.

This result reinforces one of the goals of the model-based thinking strategy, which is represented in facilitating the students' experience and directing them from the thinking of novices to the thinking of experts by helping them construct the deep foundation of physical knowledge, forming the conceptual framework for it in an organized way, and organizing and strengthening the process of retrieval and use for knowledge construction (Ryan, 2013).

It also enhances the learner's ability to use models to represent his imagination and perception of physical phenomena and the related concepts, develop evidence and arguments for discussion, defend or refute conceptual ideas, and teach him how to scientifically negotiate these phenomena, concepts and the scientific model (Chen et al., 2016).

Second Question

To verify the second hypothesis of the research, which states: "There are no statistically significant differences at the significance level 0.05 between the mean scores of the students in the two groups: experimental and control in inquiry thinking skills test".

The "T" value was calculated to compare the mean scores of the experimental and the control groups in the post-application of the inquiry thinking skills test as a whole and its sub-skills, and the value of the effect size was calculated using the coefficient (**Table 5**).

Table 5 indicates that there are statistically significant differences 0.05≥α between the mean scores obtained by the experimental and the control groups in the inquiry thinking test and its different skills favoring the experimental group (this indicates rejecting the null hypothesis) and accepting the alternative hypothesis "There is a statistically significant difference at the level 0.05≥α between the mean scores obtained by the two groups: the experimental and the control groups in the post-application of the inquiry thinking skills as a whole and its different skills (using meaningful questions, collecting and analyzing data, interpreting the results using evidence, presenting and evaluating the results, the test as a whole) favoring the experimental group."

Table 5 shows that the effect size is greater than 0.8 for each skill of the inquiry thinking skills test and the test as a whole. This indicates that the effect size of the experimental treatment (model-based thinking strategy) in developing inquiry thinking skills is high, and this can be due to the fact that the model- based thinking strategy helps the learner develop understanding of the natural world, use the mental model as a basis for interpreting and developing understanding of the phenomena (Lee et al., 2012; Penner et al., 1998), develop complex forms of thinking, and practice modeling that develops model-based thinking (Lethrer & Schauble, 2000), construct mental representations (models) that express the scientific system or phenomenon (Bryce et al., 2016), and engage in a real practical practice of generating and evaluate scientific knowledge based on the use of modeling in science education (Gouvea & Passmore, 2017; Passmore et al., 2014).

Using models during the thinking process, revising these models, helping the learner to predict and interpret data and construct conceptual understanding, designing and implementing physical experiments, constructing real scientific meaning (Zwickl & Hu, 2015), enhancing his ability to design experimental systems, and troubleshooting (Dounas-Frazer et al., 2016), all of these goals are directed towards enhancing the learner's ability to practice inquiry thinking skills.

This result is supported by the fact that the model-based thinking strategy enhances the importance of the learner's possession of inquiry thinking skills such as generating hypothesis, planning experiments, and analyzing data. It is important for the teacher to use the teaching It is important for the teacher to use the teaching moves that support the learner's acquisition of these skills or competencies by reflecting in his teaching the behaviors of scientists when they engage in the practice of scientific investigation as an aim to increase the quality of physics education (Anderson, 2002; Hasse et al., 2014).

This result is consistent with the results of previous studies, which concluded that it is possible to develop inquiry thinking skills "using meaningful questions - collecting and analyzing data - interpreting results using evidence - presenting and evaluating results" by using teaching strategies that help the learner to develop his understanding of the scientific aspects of the world through the practice of activities based on investigation and the construction of mental models that express scientific phenomena (Beltrán, 2018; Familari et al., 2013; Ješková et al., 2016, 2022; Kazeni et al., 2018; Kruit et al., 2018; Lati et al., 2012; Mustafa & Trudel, 2013; Ozturk, 2021; Polyium et al., 2018; Wang et al., 2015).

The superiority of the experimental group in the inquiry thinking skills can be due to the fact that using the model-based thinking strategy enhances the scientific investigation and includes the appropriate knowledge required for the investigation, as well as enhances the students' ability of to use the different methods by which scientists study natural phenomena, suggest evidence-based interpretations, formulate and evaluate scientific explanations, and use learning activities that develop knowledge and understanding of scientific ideas (Abd-El-Khalick et al., 2004; NRC, 2000).

This result can also be attributed to the fact that the model-based thinking strategy enhances inquiry skills such as observating, collecting data, analyzing and synthesizing information, setting results in order to develop problem-solving skills, and integrating basic and integrated practical skills into the entire practical research process known as inquiry thinking skills (Harrison, 2014). The model- based thinking strategy promotes the growth of various inquiry thinking skills, such as the skill of analyzing and interpreting data from tables and graphs, identifying, understanding and using relationships between variables, selecting and controlling variables, planning procedures, and interpreting patterns of evidence (Wu & Hsieh, 2006).

In addition, this result can be interpreted in light of the stages of the model-based thinking strategy. In the stage of presenting the scientific phenomenon, the teacher uses with the students, the previous knowledge associated with it, and the learner organizes his knowledge about the ideas in the phenomenon. This stage requires him to practice inquiry thinking skills related to making organized and accurate observations and measurements using a set of tools. At the stage of generating/identifying questions about the scientific phenomenon; the learner practices asking questions about the phenomenon and defining what he observes about it, using meaningful questions that lead to investigation about the scientific phenomenon, and constructing ideas around it. At the stage of Investigating phenomena and construction of a preliminary model, the learner seeks to generate ideas related to the questions raised previously, investigate the scientific phenomenon, and generate the model that answers the questions related to the phenomenon, and link previous conceptual knowledge to the mental model that is being constructed; here, the learner

Table 6. Pearson correlation coefficient between results of physical concepts test & inquiry thinking skills test for experimental group

Variable	Number	Correlation coefficient	Significance level
Physical concepts test & inquiry thinking skills test	33	0.53	0.05

practices inquiry thinking skills associated with gathering evidence through observation and use of information sources, planning and predicting, and formulating scientific models.

While in the stage of revision the preliminary model, the learner practices research and investigation in order to reach the main knowledge and ideas that constitute the knowledge base required to construct a modified mental model of the phenomenon. Here, the learner continues to practice inquiry thinking skills represented in reviewing and revising the preliminary model, analyzing, interpreting, clarifying, conducting discussions and negotiating about mental models, criticizing and testing scientific ideas, generating testable hypotheses, generating and evaluating scientific knowledge, troubleshooting in models, and interpreting results using evidence.

Also, in the stage of modifying the model associated with the scientific phenomenon, the learner clarifies his understanding of the physical concepts and laws embodied in the model, clarifies the ideas and relationships that the model reflects, and experiments and applies the modified model in new situations. Thus, the learner practices inquiry thinking skills related to communication, discussion, reflection, and evaluation, recognizing the interpretations and mental models and their analysis, and reviewing the current scientific understanding and evidence to determine the best interpretation for the model.

Finally, in the stage of thinking "reflection" about the model, learner is allowed to construct mental representations and use them in discussing the phenomenon, giving him the opportunity to reflect on his experiences and apply his scientific understanding.

Thus, many inquiry thinking skills are practiced such as the skill of identifying the most important scientific ideas presented by the model, constructing and developing scientific explanations related to scientific phenomena, interpreting results using evidence, making predictions expected to be extracted from the model, comparing the preliminary model with the modified model, and presenting and evaluating the model.

This result agrees with what was indicated by Russ and Odden (2017) that the model-based thinking strategy not only consolidates the learning of physical facts, but also establishes the development of scientific thinking skills through which the learner can learn and deduce knowledge. It also agreed with what was indicated by Gaytan (2017) that the model-based thinking strategy supports the existence of a strong relationship between presenting the scientific phenomenon to the learner and asking a set of motivating questions that lead him to practice inquiry thinking skills while dealing with the phenomena, finding a set of ideas while practicing inquiry thinking skills, which tries to answer those questions raised about the scientific phenomenon.

Ryan (2013) emphasized that the model-based thinking strategy is a strategy in which the student interprets a situation by placing it in an internal model that it owns, helps him understand the physical situation, and enables him to predict, describe, or interpret using in the problem situation. This indicates that in this strategy the learner practices a number of inquiry thinking skills such as interpretation, constructing mental models, predicting, and asking meaningful questions that would bring about transformations, modifications, additions, or revisions to the mental model.

Generally, this result can be attributed to the fact that the model-based thinking strategy enhances a wide range of inquiry thinking skills when the learner constructs different mental figurative, conceptual, analogical mathematical, hypothetical, and deductive models.

These skills include asking questions, predicting, planning research, designing and conducting inquiry, collecting, recording, classifying and presenting data in a variety of ways, analyzing, recording results using simple language, graphs and specific formats, interpreting, clarifying, communicating, debating, reflecting, evaluating, and defending scientific arguments and evidence, identifying and analyzing alternative interpretations and models, this is in contrast to the use of traditional methods in teaching physics that do not enhance the learner's ability to construct mental models and representations related to the phenomenon, design and implement experiments, and do not develop more complex forms of thinking, and do not allow him to interpret the reason for the behavior of the phenomenon or its occurrence, and does not allow him to engage in it in real practice with the aim of generating and evaluating scientific knowledge.

Third Question

To verify the third hypothesis of the research, which states, "There is a positive correlation between the scores of the experimental group in the physical concepts test, and their scores in the inquiry thinking skills test in physics". The researcher used Pearson correlation coefficient, as shown in **Table 6**.

Table 6 shows that the correlation coefficient of the experimental group reached 0.53, at a significance level of 0.05. There is therefore a positive correlation relationship between the physical concepts and inquiry thinking skills among first-grade high school students who were taught using model-based thinking strategy.

It means that the model-based thinking strategy enhances the learner's ability to analyze, construct and shape mental models, revise them, and raise questions about the basic properties of physical phenomena, which leads them to understand the physical phenomena and concepts related to these phenomena. It also enhances the formation of physical concepts represented in representation, classification, assembly, disassembly, generalization, identification, and finding correct representations, which are essential components of inquiry thinking skills (Nowack & Casperson, 2014). It also enhances in the learners' abilities, which is abstracting and extracting the most important ideas and concepts contained in the physical phenomena, constructs mental models, develops scientific interpretations, and makes predictions expected to be extracted from the model (Dounas-Frazer et al., 2016; Gaytan, 2017; Russ & Odden, 2017).

These abilities include a set of inquiry thinking skills that play a role in developing physical concepts. In addition, the questions posed by the teacher in the model-based thinking strategy have positive learning outcomes for the learner represented in constructing meaning around physical concepts. It provides him with opportunities to practice inquiry thinking skills associated with constructing mental models that express scientific phenomena, evaluate and modify those models, interpret, present and evaluate results, which have an impact on developing physical concepts (Gouvea & Passmore, 2017). The model-based thinking strategy is one of the strategies that enhance the learner's knowledge of scientific phenomena, and motivate him towards collecting data and using it to answer and interpret scientific phenomena, and to ask thought-provoking questions centered on the events of the natural world and related to the content of learning, and to solve problems, through the practice of investigation, which is reflected in the development the ability to understand physics (Abrahams & Millar, 2008; NRC, 2000).

This result can be interpreted in the light that the model-based thinking strategy is one of the strategies that enhance inquiry thinking and problem-solving skills while constructing mental models as it contains stimulating and thought-provoking teaching procedures that enhance the learner's scientific investigation, help him develop the skills of the scientific process, and develop physical concepts (Minogue et al., 2010). The model- based thinking strategy is compatible with scientific inquiry- based learning approaches in its mission of the scientific inquiry, as it is a continuous process for life, and that inquiry skills are essential to equip the learner to think critically in solving problems and motivate him to learn scientific concepts.

This result supports that the most important element when learning physical concepts is that the learner becomes able to ask questions, collect data, think through evidence, construct interpretations in light of the data collected, transfer these interpretations and convey them to others, develop his own questions and design inquiry, which enables him to answer these questions that lead him to understand (Lee & Shea, 2016).

This result is consistent with what was indicated by Al-Araimi et al. (2018) that enhancing scientific skills such as problem-solving skills, critical and innovative thinking, decision-making, and planning for different types of scientific activity, "which are skills related to inquiry thinking" that lead the learner to discover and learn scientific concepts. It also agrees with what indicated by Ertikanto et al. (2017) and Tekin and Mustu (2021) that leaning science must include investigative processes so that the learner acquires a conceptual understanding of science and scientific skills and improves his engagement in the conceptual learning process. Learning and obtaining physical concepts and achieving a deep understanding of the learning material depend on the degree of the learner's engagement in practicing science process skills (inquiry skills). It also agrees with what indicated by Windschitl (2000) that inquiry thinking skills such as collecting, synthesizing, and analyzing information, selecting and controlling variables, planning procedures, interpreting patterns of evidence, and developing new products promote the growth of conceptual cognitive structures, applying these structures in solving new problems and constructing scientific interpretations around physical concepts.

This result confirms what was indicated by Eberbach and Crowley (2009) that science teaching should be concerned with the development of skill and knowledge together, because knowledge represented in facts, concepts, theories, and principles is a prerequisite for skill development, because when the students practice inquiry skills such as imposing hypotheses, observation, evaluation of scientific evidence, and reaching conclusions, the previous knowledge has a great impact on skill development, and at the same time, practicing inquiry thinking skills enhances the development of concepts.

This result confirms what Harlen (2014) indicated, that model-based inquiry learning develops inquiry thinking skills, enhances the understanding and the development of scientific concepts and principles. Thus, model-based thinking is a combination of mental processes and practical activities that help learning physical concepts.

The statistically significant positive relationship between inquiry thinking skills and developing physical concepts can be attributed to what was indicated by Lee and Shea (2016) that the scientific ideas "concepts" gained through applying model-based thinking strategy is the best in terms of learning and retention compared to the traditional education approaches, because in the light of this strategy, the learner becomes able to construct his own knowledge based on his real experience, ask questions, and provide him with opportunities for repeated exposure to science concepts "physics" and allow him reinforce the conceptual understanding until it become integrated into long-term memory. In the light of the model-based thinking strategy, the learner is allowed to be engaged in explanatory activities and investigative learning, and to develop a set of mental skills that enable him to construct an understanding of scientific concepts (Windschitl, 2000). It also allows them to develop a range of inquiry skills such as interpretation and using evidence that can support or contradict scientific theories, construct mental models, and justify theories that interpret the phenomenon itself. These skills are among the most basic skills that define scientific thinking, which leads to form and interpret scientific concepts (Kuhn & Dean, 2004).

Generally, the relationship between the dependent variables (inquiry thinking skills - developing physical concepts) among the experimental group is due to the strong independent variable (the model-based thinking strategy), which enhances the practice of inquiry thinking skills such as constructing scientific interpretations for a phenomena, and building logical relationships between evidence and scientific interpretations, which develops students' physical concepts among.

CONCLUSIONS & RECOMMENDATIONS

The results showed firstly, there are statistically significant differences at the significance level 0.05 between the mean scores of the students in the two groups: experimental and control in the physical concepts test favoring the experimental group. Secondly, there are statistically significant differences at the significance level 0.05 between the mean scores of the students in the two groups: experimental and control in the test of inquiry thinking skills test favoring the experimental group. Thirdly, there is a positive correlation between the scores of the experimental group in the physical concepts test, and their scores in the inquiry thinking skills test. According to these results, it is obvious that using the model-based thinking strategy in the teaching physics is effective in developing students' physical concepts and inquiry thinking skills.

Accordingly, in the light of the results, the research presents the following recommendations: Activate the different teaching strategies such as the model-based thinking strategy in which the learner interprets the physical situation, constructs predictions or interpretations, using them in the physical situation, and designs, constructs and forms his own model of physical phenomenon in order to develop his understanding of the natural or material world, as well as using models as a basis for interpreting physical phenomena, and using concept extraction activities that are designed to extract conceptual models that he uses continuously and repeatedly in solving problems. It is necessary for curriculum planners to plan physics curricula in the light of the model-based thinking strategy, which develops learners' physical concepts and inquiry thinking skills. It is also necessary to issue a teacher's guide that includes models showing how to apply the model-based thinking strategy in teaching physical concepts, as well, hold workshops and training courses for physics teachers and supervisors to train them on how to apply the model-based thinking strategy in teaching physics as it is one of the effective strategies that is based on the development of complex forms of thinking through models, and allow the learner to build different forms of thinking, and provide mental modeling, and troubleshooting conceptual understanding. In addition, training the learner to identify physical phenomena and concepts and linking them through the processes of forming concepts represented in representation, classification, assembly, disassembly, generalization and definitions, and finding correct representations.

The current research presents some suggestions, represented in conducting many research in physics teaching and learning, such as investigating the effectiveness of using model-based thinking strategy in developing high school students' physical concepts and other variables such as critical thinking skills, divergent thinking, solving physical problems, and emotional thinking, and investigating the effectiveness of using model-based thinking strategy in constructing mental representations and developing high school students' scientific and engineering practices and rapid learning skills in physics.

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