

Misconceptions and Science Education

Ayşe Ceren ATMACA-AKSOY

Necmettin Erbakan University

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Introduction

Concept

Individuals face many different events in their daily lives. Some of these events may involve different challenges or problems. Individuals need various information to solve these problems. This knowledge consists of concepts. Concepts serve as the basic structure for knowledge. Individuals will make sense of this information correctly if they structure the concepts appropriately. Scientific knowledge is knowledge produced from relationships among concepts. In this context, if a general definition is made, concepts can be expressed as the qualities of categories for definitions that reflect the relationship of individuals with the universe. Based on this definition, it would be reasonable to say that concepts are necessary to understand and comprehend the functioning of the universe (Riche, 2000). Concepts are structures that do not exist in concrete reality. They are the models of a phenomenon, thought or object in our minds. In this context, in the concrete world, we encounter not concepts but examples or representations of these concepts. In this case, in order to learn concepts, these representations and models should be well known. As mentioned before, acquiring knowledge is possible by learning concepts. Concepts are structures that organize mental processes in the learning process. The structuring of knowledge in the minds of individuals takes place in this process (MacLellan, 2005).

Although concepts have certain characteristics, these characteristics may change over time in order to adapt to the requirements of the current era. In this context, concepts can be redefined. These characteristics are;

- Concepts have a starting point, the original. These starting points are the first form of the relevant concept in the mind of the individual. Concepts have an origin in the minds of individuals.
- Concepts are classified in terms of their properties.
- The structures we call concepts are formed by direct or indirect observation of the properties of events, phenomena or objects. With direct observations, concrete features of concepts are formed. Indirect observations form the intangible properties of concepts.
- In some cases, certain features may be attributed to more than one concept.
- It is in close relationship with language. The structures we call concepts are expressed with words and vocabulary. In this context, concepts are also in close relationship with cultures. Concepts are affected by all elements affecting culture and gain meaning.

- Concepts are affected by social and individual differences. Changes in individuals' lives and the society they live in are reflected in the way they understand phenomena. Therefore, concepts may differ (Glock, 2010; Ozmen, 2017).

Concepts are structures that are made sense of and shaped in the minds of individuals. Some procedures are used in the process of making sense of and shaping concepts in the minds of individuals. Generalization is one of them. The process of generalization can be expressed as the process of classifying related objects, phenomena, thoughts or behaviors based on similar characteristics and naming these classes. There are many factors affecting this process. Improper realization of the generalization process causes the related concept not to be understood correctly. In this case, the concept is learned incorrectly. The fact that there are few observations and experiences in the generalization process is one of the factors that increase the likelihood of incorrect generalization. More or less generalization than necessary may cause complexity and uncertainty about the meaning of the concept and its relationship with other concepts. Another process used in the formation of concepts is the discrimination process. In this process, individuals base the concepts they are interested in on the different properties of phenomena or objects, that is, their dissimilar properties. The discrimination process is very important for the emergence of clarity between concepts (Wathall, 2016).

Individuals begin to observe the world and their environment from the moment they are born. As a result of these observations, they develop a perspective on events and phenomena and form their thoughts and ideas. The knowledge and ideas that individuals acquire through their own experiences, experiences and experiences may not have the same meaning as scientifically accepted concepts. The wrong meanings attributed to concepts in these contradictions appear as misconceptions. In its most basic definition, misconceptions are the interpretation of concepts in the minds of individuals in a way that is far from scientific and contradicts scientific acceptances (Baxter, 1985; Sewell, 2002).

Misconceptions

Learning is not only a process that takes place in educational institutions. Individuals acquire various knowledge by observing their environment and the world from the moment they are born. When they come to educational institutions, they come with a certain amount of prior learning and prior knowledge. This prior knowledge that individuals acquire as a result of their experiences plays an important role in the processes of making sense of new concepts and structuring scientific knowledge. The learning process is realized by restructuring prior knowledge in the mind with new concepts. In this context, an incorrect interpretation of the concepts in the old and prior knowledge will also affect the person's subsequent learning (Piaget, 1985). Learning is a lifelong process starting from the birth of an individual. The individual who learns throughout his/her life may occasionally learn incompatible with scientific facts under the influence of past experiences, prior knowledge or many environmental factors (Leonard et al., 2014). These learnings by individuals that contradict scientific facts have been named in different ways by different researchers over time. Some of these are;

- Pre-concepts (Ausubel et al., 1968; Clement, 1993)
- Alternative Frameworks (Driver & Easley, 1978),

- Conceptual Frameworks (Driver & Erickson, 1983),
- Children's Science (Gilbert et al., 1982),
- Prejudices (Osborne & Freyberg, 1985),
- Misconceptions (Clement et al., 1989; Novak, 1988),
- Intuitive Concepts (Bar, 1989),
- Misunderstandings (Helm, 1980; Spada, 1994),
- Students' Definitions (Nakhleh, 1992),
- Conceptual Difficulties (McDermott, 1993),
- Phenomenological Principles (DiSessa, 1993),
- Children's ideas (Osborne et al., 1993),
- First Concepts (Chi et al., 1994),
- Naive Beliefs (Caramazza et al., 1980),
- Ideas (Kuiper, 1994),
- General Sensory Concepts (Halloun & Hestenes, 1985; Spada, 1994),
- Faithless Beliefs (Hills, 1989),
- Alternative Concepts (Atwood & Atwood, 1996; Klammer, 1998),
- Wrong Conception (DiSessa & Sherin, 1998),
- Mental Models (Greca & Moreira, 2001; Vosniadou, 1994),
- Common Sense Concepts (Chi, 2005),
- Immature Thoughts (Nehm & Ha, 2011)

Misconceptions are the structures formed as a result of individuals' unscientific interpretation of their environment, which they discover with their own experiences and experiences starting from an early age. The concepts obtained as a result of the individual's interpretation of the world with a non-scientific thought system also emerge as concepts that contradict scientific facts. Concepts that are made sense of in individuals' mental processes with reasoning systems that are far from scientific facts cause misconceptions (Gooding, & Metz, 2011). There are many individual factors that cause misconceptions. Individuals' past experiences, experiences and experiences, values and ethical judgments, norms and beliefs are some of them. Some learning under the influence of these factors may cause misconceptions because it is far from scientific (Griffiths & Grant, 1985).

Misconceptions are not the wrong answers that individuals give randomly in the face of an event or a question. The reason for misconceptions is not the lack of knowledge present in the individual. Misconceptions are a situation that arises as a result of incorrect or incomplete structuring of the concept in the mental processes of the individual. Individuals use their own unique thought systems in defining and making sense of their environment, which causes each individual to show differences in expressing their environment. If there are faulty or missing areas and gaps in this thought system, individuals tend to misinterpret concepts. This situation forms the basis of misconceptions. If individuals in the learning process understand a concept differently from its scientifically accepted meaning and learning is realized, this will affect their current and future learning and cause misconceptions (Mishra, 2020).

Misconceptions and errors are often confused. Misconceptions and errors are not the same content. All misconceptions are errors, but not all errors are misconceptions. Misconceptions are one of the reasons why errors occur. Misconceptions are constructs that cause erroneous scientific knowledge as a result of misunderstanding

and structuring of the concept (Holmes et al., 2013). Individuals are not aware that their misconceptions are unscientific and inaccurate knowledge that contradicts scientific facts. From the viewpoint of individuals, that information is scientific, correct information. As a result of this situation, as long as misconceptions are not identified and corrected, they will cause the individual to perform wrong learning throughout his/her life. There are certain characteristics of these structures that are far from scientific and contradictory in the minds of individuals (Ibrahim & Sunanto, 2022).

These features have been addressed by various researchers at different times with different contents. In his study, Nachtigall (1990) listed the characteristics of misconceptions as individual-specific, sufficient in explaining limited events, inconsistent among themselves and with scientific knowledge, incoherent, resistant, and arising from individual, environmental and technological factors. The researcher added that these constructs can emerge in different ways in the same subject. Wessel (1998) emphasized in his study that misconceptions are structures that are formed as a result of individual experiences and can be seen in every individual without discrimination. Güneş (2005) emphasized in his study that misconceptions are resistant structures and are difficult to correct with traditional methods. The researcher stated that these structures cannot be detected with classical questions asked to individuals and that these structures have individual differences because they develop through the experiences of the individual.

Causes of Misconceptions

Taylor & Kowalski (2004) defined misconceptions as unscientific constructs that are contrary to scientifically accepted facts obtained through personal practice and experience. The acceptance of these structures as correct knowledge by individuals causes these structures to be resistant to change. Misconceptions, which are accepted as a scientific fact by the individual and take place in his/her mind, may cause the new information to be learned to be ignored or distorted. This situation may cause the misconception to continue or strengthen its existence in the mind of the individual. In this context, it is very important to understand the nature and sources of misconceptions in order to identify and correct these misconceptions (Menz et al., 2021).

Committee on Undergraduate Science Education (1997) listed the sources and causes of misconceptions as; information obtained by individuals from non-scientific sources, perspectives that contradict scientific facts, individuals trying to find solutions to the contradictions occurring in their mental processes with wrong or weak models, and the difference between daily and academic language. Önen (2005) listed the reasons for misconceptions in his study;

- Prejudices and unscientific pre-knowledge present in the individual,
- The relationships among concepts are not well structured in the learner's mind,
- The instructor uses unscientific and outdated teaching methods,
- The individual is not included in the learning environment, the individual experiences a passive teaching process,
- Failure to concretize intangible concepts

- Student misinterpretation of the differences between daily language and academic language,
- Non-scientific knowledge acquired as a result of daily experiences,
- Misinterpretation of erroneous information resulting from the misunderstanding of concepts,
- Teaching in classroom environments that are not suitable for teaching,
- Inappropriate readiness of the learner, teacher and course material,
- Not associating the acquired knowledge with daily life, not establishing a connection with daily life.

In another study on this subject, Costu et al. (2007) stated the reasons for the occurrence of misconceptions in six items in general. These are; incorrect completion or interpretation of missing information in the learner's mind, experiments conducted for concretization, methods used in the presentation of course content, prior knowledge and experiences of the individual, textbooks used, failure to establish relationships between words and terms. The researchers emphasized that incompatibility, inaccuracy or deficiency in these six factors would cause misconceptions in the learner.

The reasons for the formation of misconceptions are that the teaching does not reach maturity in the learner's mind, new learning is carried out without determining the status of the individual's prior learning, incompatible, different expressions and visuals are used for a concept, the material used is not suitable for the nature and characteristics of the concept, generalizations made more or less than necessary, memorized information, teaching too many concepts at the same time, insufficiency of prior knowledge, inability to establish a relationship between new and old concepts. Incomplete or incorrect information in teaching materials such as textbooks and posters used as resources in lessons, content and visuals that cause misinterpretation, and incorrect information obtained from non-academic pages or sites on the internet are among the elements of today's technological age that cause misconceptions. In addition, the instructor's presentation of his/her own interpretations and explanations to the learner as scientific knowledge, the use of foreign terms with unknown meanings, incomplete, inaccurate, incompatible or outdated materials are among the factors that cause misconceptions (Taylor & Kowalski, 2014).

Methods Used in Determining and Eliminating Misconceptions

Misconceptions are resistant structures that are closed to change. In this context, they are permanent. Misconceptions are very difficult to detect, eliminate and correct. However, it is imperative to correct these misconceptions in order to realize learning in a correct and scientific way. The first step to be taken to correct misconceptions is to identify these misconceptions clearly and accurately. Many different methods have been used to identify misconceptions. Since some of these methods have more disadvantages than others, their use is not recommended today. Examples of methods used to identify misconceptions include interviews, multiple-choice tests, POE (predict-observe-explain) method and progressive diagnostic tests (Maharani et al., 2019; Maskill & Cachapuz, 1989; Liew & Treagust, 1994; Putri et al., 2021).

Interview

The interview method is an effective method used to determine an individual's structures such as feelings, thoughts, attitudes and beliefs. This method is a process carried out by two individuals expressing themselves verbally. In this process, communication is usually established with the question and answer technique. Although it is an effective and common method in determining misconceptions, the analysis and data collection process takes a considerable amount of time (Chen et al, 2009).

Multiple Choice Tests

Multiple-choice tests are one of the methods used to identify misconceptions. These tests have the advantages of collecting and analyzing a large number of data in a short time. However, the use of these tests to determine misconceptions is not preferred today due to the fact that these tests cannot determine the reason for giving the answer and the questions are closed-ended, that is, they force the student to choose one of the available options. Since the reason for the student's answer cannot be determined in multiple-choice tests, it does not provide information about the cause of the misconception. In this case, it is not clear whether the error is a misconception or a lack of knowledge (Cakır & Aldemir, 2011).

Predict-Observe-Explain Method

The POE method is one of the methods used to identify misconceptions. The first step of this strategy is the guess phase. At this stage, the learner is presented with a situation and asked to make a prediction. The second stage is the observation stage. At this stage, learners make observations through experiments and applications. They obtain information. The last stage is the explanation stage. At this stage, learners compare their predictions in the first stage with the results in the observation stage. If there is a discrepancy between predictions and observations, they try to explain the reasons for this discrepancy (Kibirige et al., 2014). In this context, misconceptions in learners can be identified with this method. With the comments and explanations they will make during the explanation phase, information about the causes of these misconceptions will also be revealed (Chen et al., 2018).

Progressive Diagnostic Tests

Progressive diagnostic tests are also one of the widely used methods to identify misconceptions. Although progressive diagnostic tests appear in the literature as two-, three- or four-tier tests, four-tier diagnostic tests are more in demand nowadays. Two-tier diagnostic tests have all the advantages of multiple-choice tests and also provide the reason for the student's answer. The first stage in these tests is a classic multiple-choice question. The second stage asks for the reason for the answer given in the first stage. The second stage can be multiple-choice or open-ended, sometimes both. The disadvantage of these tests is that they do not question whether the student is sure of his/her answer. This causes these tests to be unable to distinguish between lack of knowledge and misconceptions. Two-tier tests were updated and three-tier tests were created. The difference of the three-tier tests from the two-tier tests is the addition of a confidence step as the last step. However, the

fact that this confidence step is single does not provide clarity about whether the individual is sure of his/her answer to which step. This is a disadvantage of three-tier tests. Finally, in order to overcome the disadvantages of three-tier tests, four-tier tests were created with the addition of the second confidence step. In the four-tier tests, the confidence steps added after the content and reasoning steps provide clear information about which of the answers the individual is sure of or not. With the four-tier diagnostic tests developed, 12 types of lack of knowledge, false positives, false negatives, scientific knowledge and misconceptions can be identified. The disadvantages of four-stage tests are that they take a long time to administer and analyze, and the possibility of the answers of first and third stages affecting each other (Caleon & Subramaniam, 2010a; Caleon & Subramaniam, 2010b; Sreenivasulu & Subramaniam, 2013; Taslidere, 2016; Treagust & Duit, 2008).

What needs to be done after determining misconceptions is to eliminate these misconceptions. Unless the misconceptions are eliminated, they will pose a risk for the future learning of the individual and will cause mislearning. In this context, the elimination of misconceptions is very important for the continuation of education and training activities in accordance with their purpose. Many different methods are used to eliminate misconceptions. Concept maps, conceptual change texts, concept cartoons are examples of methods commonly used to eliminate misconceptions.

Concept Maps

Concept maps are one of the methods used to ensure meaningful learning (Martin et al., 2000). Concept maps provide learners with the opportunity to associate new concepts with existing concepts while acquiring new concepts, and in this context, to realize meaningful and deep learning. It presents the relationships between concepts with a holistic approach. In addition, as a visual material, it enables the concept or information to take place concretely in the mind (Liu et al., 2009; Tekkaya, 2003).

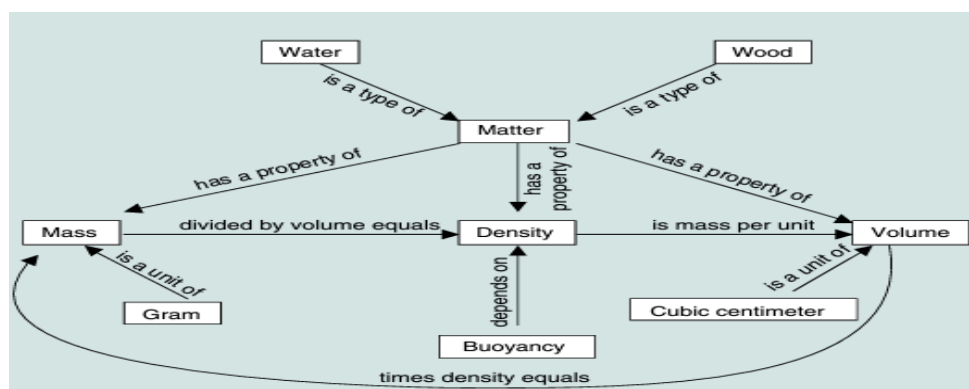


Figure 1. Concept Map on Density and Buoyancy (Vanides et al., 2005)

Conceptual Change Texts

The aim of conceptual change texts is to change the wrong information available in the learners with correct information. Conceptual change texts are texts that clearly reveal the incompatibilities and contradictions between scientifically validated knowledge and misconceptions. In conceptual change texts, the misconception existing in the learner is included in the text. The difference between misconceptions about the related concept and scientific knowledge is emphasized. Thus, the learner

realizes his/her misconception and this misconception is eliminated with scientific knowledge (Beerenwinkel et al., 2011; Hynd, 2001).

Concept Cartoons

Concept cartoons are drawings prepared with the aim of arousing curiosity in the learner, creating a discussion environment and distinguishing between correct scientific knowledge and misconceptions (Long & Marson, 2003). There are several characters in concept cartoons. The dialogues between these characters emphasize the differences between correct and incorrect information. While one of the characters in the cartoon defends the scientifically valid idea, the others defend ideas that are not scientifically valid and contain misconceptions. In this context, learners can clearly see the difference between scientific and non-scientific ideas and eliminate their existing misconceptions (Morris et al., 2007).



Figure 2. Concept Cartoon on Nutrient Sources of Plants (Ekici et al., 2007)

The Importance of Misconceptions in Science Education and Examples

All efforts to understand one's environment, the structure and functioning of the world in which one lives are defined as science. Individuals have to understand the order that exists in their environment and the functioning of this order in order to continue their lives. Existing knowledge can be made sense of by understanding this order. In this context, new scientific knowledge is produced. Science is a branch of science that includes many sub-disciplines. Interdisciplinary relations are very important for science. Science is life itself (Fuller, 2004).

This is the age of knowledge and technology. Therefore, it is the age of science. New information is produced every day and new inventions and discoveries are made. It is one of the duties and responsibilities of the science discipline that individuals and societies can follow and keep up with the developments and changes in science and technology, in short, to have the literacy skills of these fields. In this context, the realization of science education in accordance with its purpose, correct and complete is very important in terms of social as well as individual (Emrahoğlu & Ozturk, 2010). The sole purpose of science education is not only to transfer sub-disciplinary and interdisciplinary knowledge to individuals. Science is a living discipline. In this context, it is one of the aims of science to provide individuals with

skills and behaviors appropriate to the requirements of the age in which they live. Individuals who have received a well-equipped science education continue their lives as individuals who are open to change and development that may occur in their environment, are productive, and have 21st century skills. In this context, they can use all the knowledge, skills, attitudes and behaviors they have gained in a beneficial way for their nation and the whole world (Afandi at al., 2018; Yıldız & Zengin, 2021). The importance of science education has been recognized by all societies. In this context, various methods and strategies have been developed over time to provide effective and efficient science education. When we look at today's education system, it is seen that concept-oriented teaching and education has gained importance. This situation necessitates the correct and complete teaching of key concepts in science (Wright & Perna, 1992).

Science contains a large number of intangible concepts due to its disciplines and nature. One of the main reasons why science is known as a difficult science is these intangible concepts. When learners do not make sense of intangible concepts in their minds adequately and correctly, they may create incomplete learning or misconceptions. This situation leads to failure (Soechoarto at al., 2019). There are many examples of misconceptions in science disciplines. As mentioned before, science is a complex science involving interdisciplinary relationships. In this context, it contains many intangible concepts. Misconceptions that arise as a result of structuring and interpreting these concepts away from scientific understanding are very common in science education. As in all educational sciences, the biggest obstacle to the effective and efficient realization of science education is the misconceptions existing in individuals (Günbatır & Sarı, 2005). Some examples of misconceptions identified by various studies and researchers in science disciplines are presented below. Three examples were selected for each sub-discipline.

Examples of misconceptions in Physical Science;

- Force is directly proportional to speed, not acceleration (Eryılmaz & Tatlı, 2000).
- Energy cannot be stored (Solomon, 1985).
- If an object is moving, there are forces acting on this object in the direction of its motion (Kolçak at al., 2014).

Examples of misconceptions in Chemistry Science;

- Electrons have a positive charge (Özmen, 2004).
- The shells in which electrons are embedded are called atomic orbitals (Park & Light, 2009).
- When gases are produced from the combustion reaction of a liquid and a solid, the total mass decreases even if the system is closed (Chang at al., 2010).

Examples of misconceptions in Biological Science;

- Rain falls when clouds evaporate (Cardak, 2009).
- While all animal cells are independent of each other, plant cells are connected to each other by cell walls (Dikmenli & Cardak, 2004).
- Fermentation is respiration without oxygen (Sadava at al., 2014).

Examples of misconceptions about Astronomy Science;

- The biggest star is the Pole Star.
- All stars are white in color.
- All objects that can be seen in space are planets (cited in Keles & Babaoğlu, 2022).

Examples of misconceptions in Environmental Science;

- The greenhouse effect is a completely artificial phenomenon (Atmaca Aksoy, 2022).
- The main reason for the increase in skin cancer cases is global warming (McCuin at al., 2014).
- The greenhouse effect is a purely anthropogenic phenomenon (Fajarini at al., 2018).

Examples of misconceptions about Earth Science;

- There are no volcanoes in regions with cold climates (Dove, 1998).
- Summer is warmer than winter because the earth is closer to the sun in summer (Schoon, 1992).
- Earthquakes occur in regions with hot climates (Mark, 2013).

When the literature is examined, it is seen that many researchers have carried out studies to identify and eliminate misconceptions in terms of science disciplines. Misconceptions are the most serious obstacle to science education. The fact that these structures are resistant and permanent structures creates a risk for the current and future learning of the individual and ensures that education and training is not realized in an effective and efficient manner in accordance with its purpose. In this context, individuals who have learned incorrectly will use this unscientific knowledge in their daily lives as long as they live and even transfer it to other people. This situation reveals the importance of identifying and eliminating misconceptions (Yagbasan & Gulcicek, 2003).

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About the Author

Ayse Ceren ATMACA-AKSOY, PhD, is a research assistant at Necmettin Erbakan University, Ahmet Keleşoğlu Faculty of Education, Department of Science Education. She completed her doctoral education at Hacettepe University, Department of Science Education in 2022. Her research interests are sustainable development, environmental education and misconceptions.

E-mail: acatmaca@erbakan.edu.tr, **ORCID:** 0000-0002-4908-7157

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of paper titled “**Misconceptions and science education**” belongs to the author