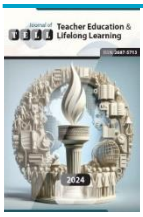

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Determination of Secondary School Students' Misconceptions about the Concept of Seed with the Four-Tier Misconception Diagnostic Test[1]

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ABSTRACT

Studies show that students have difficulty understanding topics such as fruit formation, germination and seed dispersal. The concept of seed is perceived as a general concept by students and its boundaries cannot be drawn exactly. In this context, the study aimed to determine the misconceptions of 12th grade secondary school students about seeds by developing a four-tier concept diagnostic test. For this purpose, a four-tier multiple-choice seed concept diagnostic test was developed for 12th grade secondary school students. The four-tier seed concept diagnostic test consisted of 11 questions and had a 3-factor structure. As a result of the analysis, this test was found to be valid and reliable. 30 different misconceptions were revealed with the four-tier seed concept diagnostic test. The results of the study showed that approximately one fourth of the 12th grade secondary school students had misconceptions about the concept of seed, and the rate of three of the misconceptions was above 10%. This study, which was conducted on 12th grade secondary school students, should also be conducted on different sample groups, and various studies should be conducted to eliminate the misconceptions determined in this study.

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[1] *This article was produced from the first author's master's thesis. The second author was the first author's master's thesis advisor and contributed to all processes of the research. In addition, the third author made great contributions in analysing the data and reporting and discussing the results with the support of the literature. For this reason, this study, in which all authors worked together, was organized with three authors. All authors contributed to the concept and design of the study. All authors read and approved the final manuscript.

INTRODUCTION

The topics such as fruit formation, seeds, seed dispersal and pollination included in plant biology require holistic and systematic thinking. Research shows that students have difficulty in understanding the topics such as fruit formation, germination and seed dispersal. In addition, with many studies has been revealed misconceptions about plants (Bell, 1985; Brown & Schwartz, 2009; Parker et al., 2012; Roy & Mohapatra, 2022; Södervik et al., 2015; Svandova, 2014; Wang, 2007; Yangin et al., 2014; Yürük et al., 2011). In the study conducted by Jewell (2002), it was revealed that students were unable to realise that all flowering plants bear fruit, and that they associated germination with the emergence of leaves rather than shoots and roots. In another study, students stated that they believed that flowers exist only to be aesthetically pleasing. It was also determined that students had vague ideas about the transport of pollen. In this context, it was understood that students had incomplete knowledge about reproduction in plants (Warwick & Sparks-Linfield, 1996). According to the results of some studies, it was found that students generally do not accept the seed as a plant structure until it grows and do not associate it with the plant (Allebone, 1995; Bell, 1981). Tamir et al. (1981) determined in their study that nearly half of the students studying in the fourth grade and above did not accept the seed or seed embryo as living. They stated that this may be due to the fact that the seed is normally in a dormant state and it is thought that it will revive when planted.

In the biology curriculum of 12th grade secondary school education in Türkiye, the concept of seed is included in the "Sexual Reproduction in Plants" topic of the Plant Biology Unit. Within the scope of this topic, students are expected to gain the following skills: (1) explaining the parts of the flower and the functions of these parts, (2) explaining fertilization and the formation of seeds and fruits in flowering plants, (3) designing experiments to observe seed germination, (4) establishing a relationship between dormancy and germination. In this unit, sexual reproduction in plants is taught through the example of a angiosperm by using visual elements, graphic organisers, e-learning objects and applications. The role of seed and fruit in the reproduction and dispersion of plants is discussed with examples. The factors affecting germination are determined with experiments (Ministry of National Education [MoNE], 2018). Although the concepts related to reproduction in plants are sufficiently included in school curricula, in a study conducted by Tunnicliffe and Reiss (2000), it was determined that the knowledge of students about plants was mostly based on their own observations and individual experiences. An interesting result of this study is that students give more importance to the information obtained from out-of-school environments or daily life rather than the education they receive in schools. Direct observations of students in daily life form the basis of their learning about plant seeds. For example, students can easily observe the dispersion of dandelion seeds in daily life. However, this observation does not contain any information about the structure and functions of the seed.

In his study, Jewell (2002) analyzed the understanding of seed concept of 75 students aged 7-11. The findings of this study showed that participants have a limited understanding of "seed" and have some non-scientific ideas about the internal structure of a seed, germination and seed formation. It was observed that plant structures, which are generally small in size, round or drop-shaped and inedible by humans are the seed model in the minds of many students.

As a result of the literature review, it was seen that students had various misconceptions about the concept of seed. Hershey (2004, 2005) mentioned the existence of misconceptions related to plant science among students and in science textbooks and made suggestions to eliminate them. Important misconceptions revealed in these studies are as follows: "All plants photosynthesize", "Oxygen is absolutely necessary for germination", "Plants are terrestrial organisms". Books, it can be stated that all seed plants have one or two cotyledons. This situation is an example of focusing on angiosperms and therefore ignoring gymnosperms. Gymnosperm seeds usually have more than two cotyledons.

Most of the seeds that can be grown have the ability to germinate if the necessary conditions are provided. Therefore, the seeds are not dormant. It is merely sedentary. Truly dormant seeds do not have the ability to germinate even if the necessary environmental conditions are met. It is a common misconception that the cotyledons of angiosperm seeds are filled with abundant endosperm or stored nutrients. For example, the small seeds of Orchidaceae have almost no nutritional tissue. Therefore, they depend on mushrooms to meet their nutritional needs (Mauseth, 2009; Reece et al., 2010).

Learning does not occur if students fail to understand scientific concepts correctly. When students learn and internalize scientific concepts incorrectly, it is called misconception (Haydari & Costu, 2021). In particular, the misconceptions that teachers have limit students' learning (Sagdic & Sahin, 2023). Today, in addition to misconceptions of teachers, the misuse of scientific concepts in textbooks and media, and the use of scientific concepts in different meanings in daily language are the main reasons for misconceptions in students. The main reasons for misconceptions are individual life, experiences and the teaching process. Misconception is not an ordinary lack of knowledge or error.

The individual who has a misconception is not only unaware of this, but also blindly adheres to this misconception and defends its accuracy with justifications. In order to change the misconception, the individual must first realize this misconception and feel uncomfortable (Hewson, 1996). Therefore, it is very difficult to change misconceptions. Detection and elimination of misconceptions are very important in terms of making the learning process meaningful. Today, many methods are used to detect and eliminate misconceptions. The most powerfull measurement tools used in detecting misconceptions are two-, three- and four-tier misconception diagnostic tests. Misconceptions can as well be determined through the agency of open-ended questions and open-ended interviews, but it is not clear whether they are lack of knowledge or misconceptions.

Due to the disadvantages of multiple-choice tests such as having a chance factor, students' inability to explain the reasons for answering, having limitation of answering, inability to determine metacognitive levels and conceptual learning, multiple-choice tests were transformed into two, three and four-tier concept diagnostic tests. Multi-tier concept diagnostic tests have been used in many studies that form the basis of the literature, such as Odom and Barrow (1995), Haslam and Treagust (1987) and Treagust (1985) and have become increasingly widespread. First, the positive results obtained from studies based on the justification of questions in multiple choice concept diagnostic tests led to the spread of two-tier multiple choice concept diagnostic tests (Treagust, 2006). Over time, three-tier and four-tier concept diagnostic tests were developed. In determining misconceptions, four-tier tests produce more realistic and concrete results than two-tier or three-tier tests (Bozdağ & Ok, 2018; Taşlıdere, 2016). Kaltakci Gurel et al. (2015) reported that in scientific studies conducted with four-tier tests, the tests reduced the rate of lack of knowledge and increased the rate of students' misconception and correct answer scores. Four-tier tests allow a clear distinction between lack of knowledge and misconceptions.

The aim of this study is to reveal secondary school students' misconceptions about the concept of seed by developing a "four-tier seed concept diagnostic test". As a result of the literature review, it was seen that there were studies on the development of multi-tier concept diagnostic tests on the subjects of plant biology, substance uptake and transport in plants (Akyurt & Akaydın, 2009; Vitharana, 2015; Wang, 2004), photosynthesis and plant respiration (Atchia et al., 2022; Haslam & Treagust, 1987; Lin, 2004; Lim & Poo, 2021; Svandova, 2014; Urey, 2018; Uzunhasanoğlu et al., 2020), reproduction in plants (Amelia, 2023) and growth and development of flowering plants (Lin, 2004). However, there were no multi-tier concept diagnostic tests directly related to the concept of seed. This formed the starting point of the study. The concept of "seed" discussed in this study is perceived as a general concept for students and its boundaries cannot be drawn exactly. Therefore, determining the perceptions in students' minds about the concept of seed and revealing existing misconceptions, if any, will contribute to the field of biology education.

Aim of the Study and Research Questions

The aim of this study is to reveal 12th grade secondary school students' misconceptions about the concept of seed by developing a "four-tier seed concept diagnostic test". The sub-objective of the study was to determine the percentages of students' scientific knowledge, lack of knowledge and misconceptions about the concept of seed on the basis of sub-dimensions. In this study sought answers to the following questions:

1. What are the factor-based values of the percentages of 12th grade secondary school students' scientific knowledge, lack of knowledge and misconceptions about the concept of seed?

2. What are the misconceptions of 12th grade secondary school students about the concept of seed that are common at 10% and above?

METHOD

Research Design

The survey model, one of the quantitative research methods, was used in this study. This study includes the development process of the "Four-tier Seed Concept Diagnostic Test" and the processes of detecting students' misconceptions about the concept of seed that are common at 10% and above.

Study Group

This study was conducted with 12th grade students studying in 6 high schools in Konya. The study group consists of 409 randomly selected 12th grade secondary school students. The study group was intent on by random sampling method among students with similar socioeconomic levels. The most important feature of this sampling method is that all units in the population have an equal and independent chance to be selected for the sample (Büyüköztürk et al., 2014). The criterion of grade is an important factor in determining the study group because the subject of "Seed" is included in detail in the "Plant Biology" unit within the 12th grade subjects of secondary education. The students studying in the 12th grade were preferred accordingly. The data of this study was obtained from the application carried out in the 2022-2023 academic year. The students forming the study group participated in the research on a voluntary basis. The study group consisted of 67% (n=274) female students and 33% (n=135) male students.

Research Instrument and Development Processes

In this study as a measurement tool a four-tier seed concept diagnostic test was developed. There are many studies on the use of multiple-choice tests in detecting misconceptions. Multi-tier tests first started as two-tier tests and were later developed and transformed into their current form. Two-tier concept diagnostic tests are based on the justification of a problem. In other words, they consists of two tiers: a question and the justification of the answer to this question. The disadvantage of two-tier tests is that it is not possible to determine whether incorrect learning is due to misconceptions or lack of knowledge. Therefore, three-tier tests were developed to eliminate the shortcomings of two-tier tests (Kıray et al., 2015). Three-tier tests include confidence tier which is additional to the two-tier tests. In the confidence tier, it is questioned to what extent the participant is sure of his/her answer. If the student gives an incorrect answer to either or both of the content or reason tiers and expresses that he/she is sure in the confidence tier, this indicates that the student has a misconception. Although three-tier tests are seen as more valid and reliable than two-tier tests, they are considered inadequate in determining whether the answer given in the confidence tier belongs to the content tier or the reason tier. For this reason, four-tier tests were developed and started to be administered (Taban & Kiray, 2022).

Four-tier tests include a confidence tier after both the reason and content tiers. First tier, the content tier, the participant's knowledge is questioned. Second tier, the confidence tier, the participant is asked to indicate his/her degree of confidence in the answer he/she gave in the content tier. Third tier, the reason tier, the participant is asked to state the reason for his/her answer in the first tier. Finally, fourth tier, confidence tier, the participant is asked to indicate his/her degree of confidence in the answer he/she gave in the reason tier. The participants' scientific knowledge (SK), lack of knowledge (LoK), false negative (FN), false positive (FP) and misconception (MC) can be determined by scoring their answers to these four tiers (Kiray & Simsek, 2021).

In this study, firstly, the possible misconceptions of secondary school students about the concept of seed were tried to be determined. In this context, 2 open-ended questions were asked to 55 12th grade secondary school students. In determining these questions used in the pilot scheme, the results obtained in the literature review and the opinions of 2 faculty members who are experts in the field of biology education who works university were used. In the first question, students were asked to define the concept of seed. In the second question, students were asked to write 5 examples of seeds. The prepared questions were administered to 55 12th grade secondary school students without any time limit so that they could express themselves comfortably. Students' answers to these questions were analyzed by the researchers. When the analysis result of the study was reported, students' misconceptions about seed were determined. The high-frequency expressions in the answers and the misconceptions that students had about seeds in the literature review were used to organize the questions and items in the concept diagnostic test to be developed. Finally, an item pool was formed by including misconceptions determined based on the experiences of faculty members.

The questions in the prepared item pool were transformed into a test with 2 options, "True" and "False", in the 1st tier (content tier). In the 2nd tier (confidence tier) consists of the options "absolutely not sure", "not sure", "sure" and "absolutely sure". In the 3rd tier (reason tier), a multiple-choice test consisting of 7 options was administered to indicate the justification of the answer given in the 1st tier. The analyses obtained from the pilot study and the results obtained from the literature review were to taken into accounted in writing the options for each questions. In the multiple-choice test, an open-ended option was added to allow the student to write his/her opinions in case the justifications given in the 3rd tier were insufficient. The 4th tier similarly constitutes the confidence tier and consists of the options "absolutely not sure", "not sure", "sure" and "absolutely sure". The test was transformed into a four-tier form by adding confidence tiers after both content and reason tiers. The opinions of three faculty members who are experts in biology education were taken and the test prepared accordingly was given its final form. Finally, the four-tier test consisting of 14 questions was named "Seed Concept Diagnostic Test (SCDT)". Figure 1 is given as an example of the questions included in SCDT.

6.1.	The statement "A seed is a reproductive cell",
	A ( ) True B ( ) False
6.2.	Of my answer, I'm Absolutely Not Sure ( ) Not sure ( ) Sure ( ) Absolutely Sure ( )
6.3.	BECAUSE, A ( ) The seed is a body cell. B ( ) The seed is a tissue. C ( ) The seed is not alive. D ( ) The plant develops from this cell. E ( ) This cell undergoes meiosis. F ( ) The seed is a gamete. G ( ) ....
6.4.	Of my answer, I'm Absolutely Not Sure ( ) Not sure ( ) Sure ( ) Absolutely Sure ( )

Figure 1. *An example question from the four-tier seed concept diagnostic test*

Data Collection

The four-tier SCDT was administered to 409 12th grade students studying in 6 high schools in Konya in the 2022-2023 academic year. Before data collection, the participants were informed about four-tier diagnostic tests. The four-tier SCDT was distributed to the students and they were asked to answer it individually, without being influenced by each other. Students were asked to answer all parts of the questions and select only one option for each tier. Students were given approximately 56 minutes to answer the test. The data obtained as a result of the study were analysed by entering them into Excel and SPSS programs.

Data Analysis

After the pilot scheme, the final administration of the four-tier SCDT was carried out and the data obtained was entered into the Excel program. Possible decisions that can be determined by analysing the results obtained from the four-tier concept diagnostic test are has been given in Table 1 (Taban & Kiray, 2022). Excel program was used to analyze the study data according to these possible decisions.

Table 1. *Finalization of four-tier test decisions*

1st tier	2nd Tier	3rd Tier	4th Tier	Four-tier test decision
True	Sure	True	Sure	Scientific Knowledge
True	Sure	False	Sure	False Positive
False	Sure	True	Sure	False Negative
False	Sure	False	Sure	Misconception
True	Sure	True	Not sure	Lack of Knowledge 1
True	Not sure	True	Sure	Lack of Knowledge 2
True	Not sure	True	Not sure	Lack of Knowledge 3
True	Sure	False	Not sure	Lack of Knowledge 4
True	Not sure	False	Sure	Lack of Knowledge 5
True	Not sure	False	Not sure	Lack of Knowledge 6
False	Sure	True	Not sure	Lack of Knowledge 7
False	Not sure	True	Sure	Lack of Knowledge 8
False	Not sure	True	Not sure	Lack of Knowledge 9
False	Sure	False	Not sure	Lack of Knowledge 10
False	Not sure	False	Sure	Lack of Knowledge 11
False	Not sure	False	Not sure	Lack of Knowledge 12

The data were analyzed by scoring them separately as scientific knowledge, misconception, false negative and false positive. In the analysis, correct answers were coded as "1" and incorrect answers were coded as "0" in the 1st tier and 3rd tiers for all questions. In the 2nd and 4th tier, the options "absolutely sure" and "sure" were coded as "1", and the options "absolutely not sure" and "not sure" were coded as "0". While calculating scientific knowledge scores, the data in which the students answered correctly to all tiers of the question, that is, the data coded as 1-1-1-1 were analyzed. When calculating the false-positive scores (correct with incorrect reasons), the cases in which the students answered correctly in the content tier but answered incorrectly in the reason tier and were sure in both confidence tiers, that is, the codings as 1-1-0-1, were analyzed. While calculating false-negative scores (incorrect with correct reasons), the cases in which students answered incorrectly in the content tier but answered correctly in the reason tier and were sure in both confidence tiers, that is, the codings as 0-1-1-1, were analyzed. While calculating the misconception scores, the cases in which the students answered incorrectly in both the 1st and 3rd tiers, but were sure in both confidence tiers, that is, the codings as 0-1-0-1, were analyzed.

After coding the data obtained by administering the four-tier SCDT, frequencies and percentages were calculated. Firstly, students' scientific knowledge, false negative, false positive and misconceptions averages related to the three sub-dimensions of the 11-item test were calculated according to possible decisions given in Table 1. Then, each of the four tiers of the test was matched and the value in percent of 30 misconceptions were calculated. In the justifications given for different questions, there may be cases where the same misconception is also included in another question. In such cases, the total misconception rate at all tiers determined to have the same misconception was calculated by dividing it by the number of questions. The list of misconceptions included in SCDT is presented in Table 2.

Table 2. *The list of misconceptions about seeds included in SCDT*

List of misconceptions		
M1	Since the seed and flower have the same genetic structure, the seed plant and the flowering plant are the same.	1.1.b,1.2.c/d,1.3.a,1.4.c/d
M2	Since a seed plant is a flowering plant and a seedless plant is a non-flowering plant, a seed plant and a flowering plant are the same.	1.1.b,1.2.c/d,1.3.c,1.4.c/d
M3	Since the seed is inside the flower, the seed plant and the flowering plant are the same.	1.1.b,1.2.c/d,1.3.d,1.4.c/d
M4	The potato plant cannot reproduce by seed because it is planted in the soil as a tuber; a tuber is not a seed.	2.1.a,2.2.c/d,2.3.c,2.4.c/d
M5	Since the potato plant does not have flowers, it cannot reproduce by seed.	2.1.a,2.2.c/d,2.3.d,2.4.c/d
M6	Potato plant does not reproduce by seeds, it reproduces asexually.	2.1.a,2.2.c/d,2.3.e,2.4.c/d
M7	A zygote is formed by fertilization of the seed because the seed is a gamete and is capable of fertilization.	3.1.a,3.2.c/d,3.3.b,3.4.c/d 6.1.a,6.2.c/d,6.3.f,6.4.c/d
M8	Zygote is formed with the fertilization of the seed because in plants, seed means zygote.	3.1.a,3.2.c/d,3.3.c,3.4.c/d
M9	In a seed plant, both male and female individuals produce seeds because seeds are necessary for the plant to reproduce.	4.1.a,4.2.c/d,4.3.d,4.4.c/d
M10	In a seed plant, both male and female individuals produce seeds because each individual can produce seeds since it bears fruit.	4.1.a,4.2.c/d,4.3.f,4.4.c/d
M11	A pine cone is a seed because a pine tree grows from each cone.	5.1.a,5.2.c/d,5.3.b,5.4.c/d
M12	A pine cone is a seed because each pine cone carries pollen.	5.1.a,5.2.c/d,5.3.e,5.4.c/d
M13	A pine cone is a seed because pine is a gymnosperm plant.	5.1.a,5.2.c/d,5.3.f,5.4.c/d
M14	The seed is a reproductive cell because the plant develops from this cell.	6.1.a,6.2.c/d,6.3.d,6.4.c/d
M15	The seed is a reproductive cell because this cell undergoes meiosis.	6.1.a,6.2.c/d,6.3.e,6.4.c/d
M16	Oxygen is absolutely necessary for germination because oxygen is the molecule that initiates germination reactions.	7.1.b,7.2.c/d,7.3.c,7.4.c/d
M17	Oxygen is absolutely necessary for germination because oxygen is essential for gas exchange and photosynthesis.	7.1.b,7.2.c/d,7.3.d,7.4.c/d
M18	Oxygen is absolutely necessary for germination because no living thing can grow and develop in an oxygen-free environment.	7.1.b,7.2.c/d,7.3.f,7.4.c/d
M19	The tulip is not a seed plant because this plant reproduces by bulbs and does not produce seeds.	8.1.b,8.2.c/d,8.3.c,8.4.c/d
M20	The tulip is not a seed plant because it reproduces by spores, not seeds.	8.1.b,8.2.c/d,8.3.d,8.4.c/d
M21	The tulip is not a seed plant because it does not have a seed since it does not have a nucleus.	8.1.b,8.2.c/d,8.3.f,8.4.c/d
M22	Sunlight is needed for photosynthesis during seed germination because the seed cannot survive in a light-free environment.	9.1.a,9.2.c/d,9.3.a,9.4.c/d
M23	Sunlight is needed for photosynthesis during seed germination because the seed meets its nutritional needs from photosynthesis.	9.1.a,9.2.c/d,9.3.c,9.4.c/d
M24	Sunlight is needed for photosynthesis during seed germination because the Sun is the primary energy source of living things.	9.1.a,9.2.c/d,9.3.e,9.4.c/d
M25	A plant that reproduces vegetatively is a seedless plant because these plants have no sexual organs, and therefore no seeds.	10.1.a,10.2.c/d,10.3.b,10.4.c/d
M26	A plant that reproduces vegetatively is a seedless plant because it does not need seeds to continue its generation.	10.1.a,10.2.c/d,10.3.c,10.4.c/d
M27	A plant that reproduces vegetatively is a seedless plant because in these plants the vegetative organ and the seed are the same thing.	10.1.a,10.2.c/d,10.3.d,10.4.c/d
M28	A dormant seed is not alive because it cannot grow and develop.	11.1.b,11.2.c/d,11.3.a,11.4.c/d
M29	A dormant seed is not alive because it does not respire.	11.1.b,11.2.c/d,11.3.b,11.4.c/d
M30	A dormant seed is not alive because it is motionless.	11.1.b,11.2.c/d,11.3.f,11.4.c/d

Ethic

For this article obtained ethics clearance from Necmettin Erbakan University Social and Human Sciences Scientific Research Ethics Committee Presidency. (Decision no:2022/462)

RESULTS

In this section, data on the reliability and validity analysis of the four-tier SCDT were presented. In addition, the frequencies and values percent of scientific knowledge, lack of knowledge and misconceptions were presented on a question and factor basis.

Reliability analysis of the test

The reliability of these four-tier concept diagnosis tests, which are used to determine both students' scientific knowledge levels and misconceptions, is calculated with two different coefficients. These are the "Scientific Knowledge Reliability Coefficient" and the "Misconception Reliability Coefficient".

Scientific knowledge reliability coefficient (First type)

This coefficient is calculated according to the scientific knowledge score of the participants. As a result of the KR-20 analysis, the first type reliability coefficient of the four-tier SCDT was calculated as 0.743.

Misconception reliability coefficient (Second type)

This coefficient is calculated according to the participants' misconception score. As a result of the KR-20 analysis, the second type reliability coefficient of the four-tier SCDT was calculated as 0.610. The fact that this ratio is higher than 0.70 in multiple-choice tests indicates that the test is reliable (Tavakol & Dennick, 2011), but this ratio may be lower in concept diagnostic tests. In concept diagnostic tests, a KR-20 reliability coefficient of over 0.60 is considered sufficient for reliability (Eryilmaz, 2010; Kaltakci, 2012). Therefore, the misconception reliability coefficient calculated for the four-tier SCDT is at an acceptable level.

Validity analysis of the test

Four different methods are used for validity in four-tier concept diagnosis tests (Taban and Kiray, 2022).

Validity 1: Correlation between participants' correct answer scores and confidence scores

In four-tier tests, the correlation between participants' correct answer scores and confidence scores expresses the extent to which the items in the test measure the desired feature. Participants who score high on the test are expected to have a high level of reliability in the confidence levels. For this purpose, 3 different correlation coefficients were calculated to ensure the construct validity of SCDT. These are,

1) First Confidence Score; Correlation between 1st and 2nd tiers

2) Second Confidence Scores; Correlation between 3rd and 4th tiers

3) Both Confidence Scores; Correlation between 1st and 3rd tiers and 2nd and 4th tiers

Before calculating the correlation coefficient, it was checked whether the variables whose relationship would be investigated had a normal distribution in order to fulfil the assumptions. According to the results obtained, it was seen that the data did not provide normal distribution ($p<.05$), therefore Spearman’s product-moment correlation, which is the nonparametric equivalent of Pearson correlation, was used. Analysis results are given in Table 3.

Table 3. *Correlations regarding the confidence levels of the test*

Confidence Scores	Spearman's rho	Sig. (2-tailed)	N
First Confidence Score	.137	.006	409
Second Confidence Scores	.241	.000	409
Both Confidence Scores	.244	.000	409

According to the results in Table 3, it is seen that the Spearman correlation coefficient in the first confidence score calculated according to the participants' answers to the 1st and 2nd tiers is 0.137. This coefficient shows that significant, positive and weak relationship between the participants' answers to 1st and 2nd tiers. It is seen that the Spearman correlation coefficient in the second confidence score calculated according to the participants' answers to 3rd and 4th tiers is 0.241. This coefficient shows that significant, positive and weak relationship between the participants' answers to 3rd and 4th tiers. The last, the Spearman correlation coefficient calculated between both confidence scores of the participants' is 0.244. This coefficient shows that significant, positive and weak relationship between both confidence scores of the participants'. Since four-tier concept diagnostic tests are very difficult, the correlation coefficients obtained between the tiers are generally calculated to be low. For this reason, a positive correlation between the 1st and 3rd tiers in four-tiers concept diagnosis tests is considered sufficient to meet the construct validity criterion of the test (Kaltakçı-Gürel et al., 2017; Kiray and Şimşek, 2021). Therefore, according to the results of the analyses, it was seen that the four-tier SCDT met the criterion of construct validity.

Validity 2: Factor analysis

Factor analysis was conducted at this stage to ensure the construct validity of the four-tier SCDT, developed to determine the misconceptions of 12th grade secondary school students about seeds. Before starting factor analysis, the suitability of the data for factor analysis should first be tested (Özdamar, 2017). In order to perform factor analysis, it is generally recommended that the measurement level of the variables be intermittent. In measurements coded with 0 and 1, that is, non-continuous measurements, programs that carry out analyses using multi-tier correlation coefficients can be preferred. In this study, since the answers of the students are coded as 0 and 1 and have two tiers, they are suitable for factor analysis using the program. There are many different opinions in the literature regarding the sample size for factor analysis. According to Kline (1994), the sample size should be twice the number of items. In this study, considering that there were 14 questions at the beginning and each question consisted of 4 tiers, it was seen that the sample size was sufficient for the minimum conditions. As another criterion for factor analysis, Kaiser-Meyer-Olkin (KMO) criterion, which takes a value between 0 and 1, was tested to check the sufficiency of the sample. According to the results obtained from the preliminary analysis, the KMO value of the four-tier SCDT was determined to be 0.698 at the beginning of the factor analysis, and it was found to be sufficient for factor analysis since it was greater than 0.60 (Field, 2005). Whether the answers to the four-tier SCDT items were independent or correlated with each other was evaluated with Bartlett's test of sphericity. The sphericity test result of $p \leq 0.05$ indicates significance (Field, 2005). The result of Bartlett's test of sphericity for the four-tier SCDT was found to be statistically significant ($p=0.00$) and it was determined that the test was suitable for factor analysis.

Explanatory factor analysis (EFA) was implemented to the data obtained from the four-tier SCDT. Initially, according to the EFA results, it was determined that the questions were grouped under 5 factors and the total variance explanation rate of these factors was 51.30%. Rotation (axis rotation) is implemented in test and scale development studies to facilitate the interpretation of the factor structure. In SPSS, varimax is mostly preferred because it is easy to interpret (Landau & Everitt, 2003; Thompson, 2004; Yong & Pierce, 2013). Therefore, Varimax, one of the vertical rotation techniques, was preferred in the study. After the rotation, the items were discarded due to the imbalance in factor loadings. The reasons for discarding these items were that they did not give significant loadings (minimum .40) to any factor (S2), although they gave significant loadings for two factors, the difference between them was less than .10 and therefore they were considered as overlapping items (S8), and each factor did not include at least 3 items (S10). EFA was repeated after each item was discarded. In the last case, a 3-factor ideal structure was formed for the four-tier seed concept diagnostic test and the final KMO value was determined as 0.714. Bartlett's test of sphericity result was again found to be statistically significant (p=0.00). In consequence of EFA are given in Table 4.

Table 4. *Findings related to the factors determined as a result of EFA*

Factor	Eigenvalue	Variance Percentage	Percentage of Total Variance
1	2.314	21.039	21.039
2	1.214	11.037	32.076
3	1.084	9.858	41.934

When Table 4 is analysed, it is seen that the test has a 3-factor structure and the eigenvalues of the factors are 2.314, 1.214 and 1.084, respectively. The explanation rates of the factors for the total variance are as follows; Factor 1 21.039%, Factor 2 11.037%, Factor 3 9.858%. In general, the factors explain 41.934% of the total variance. The lower limit of the variance explained in multi-factor structures is accepted as 40% (Karagöz, 2016). Therefore, it was seen that the total variance explanation rate was sufficient and met the necessary conditions. The question contents were analysed and a name was given for each factor covering all the questions in the factor. Factor 1 was named as "Physiology of Seed", Factor 2 as "Seed and Reproduction Relationship" and Factor 3 as "Seed and Classification Relationship".

According to the results obtained, the four-tier SCDT developed consists of 11 questions in the final case. Findings regarding the factor loadings of the questions are given in Table 5.

Table 5. *Factor loading values of SCDT*

Question No	Factors*		
	Factor 1 Physiology of Seed	Factor 2 Seed and Reproduction Relationship	Factor 3 Seed and Classification Relationship
Q9	.661		
Q7	.609		
Q3	.562		
Q11	.521		
Q6	.512		
Q2		.741	
Q8		.487	
Q5		.455	
Q1			.759
Q10			.592
Q4			.450

*: Values below .40 are not shown in the table.

According to the results obtained from the factor analysis, Factor 1 includes 5 questions (factor loading values from 0.512 to 0.661), Factor 2 includes 3 questions (factor loading values from 0.455 to 0.741), and Factor 3 includes 3 questions (factor loading values from 0.450 to 0.759). When factor loading values are evaluated (Bursal, 2017),

• For Factor 1, 1 question contributes at a very good level (Q9), 2 questions at a good level (Q3, Q7) and 2 questions at a medium level (Q6, Q11).

• For Factor 2, 1 question contributes at an excellent level (Q2) and 2 questions contribute at a medium level (Q5, Q8).

• For Factor 3, 1 question contributes at an excellent level (Q1), 1 question at a good level (Q10) and 1 question at a medium level (Q4).

Validity 3: False negative and false positive

The averages of participants' scientific knowledge, lack of knowledge, false negative, false positive and misconceptions can be obtained with four-tier concept diagnostic tests. False positive show up when participants give a correct answer to a question in the concept diagnostic test in the content tier and give an incorrect answer in the reason tier, while expressing that they are sure of their answers in both confidence tiers. False negative show up when the participants' give an incorrect answer to a question in the concept diagnostic test in the content tier and give a correct answer in the reason tier, while expressing that they are sure of their answers in both confidence tiers. False negative and false positive averages the concept diagnostic test are used as a criterion for the validity of concept diagnostic tests. According to Hestenes and Halloun (1995), false negative and false positive averages should be below 10% for concept diagnostic tests to be valid. In the analyses conducted after the administration of the four-tier SCDT developed in this study to 12th grade secondary school students, it was determined that the average of positive false was 8.85% and the average of false negative was 1.51%. Since both values were below 10%, they were found to be sufficient for validity.

Validity 4: Expert opinion

The expert opinions of two lecturers who are experts in biology education were used to determine the questions used in the pilot scheme. During the preparation of the questions and finalization of the test, expert opinions were received from 3 different lecturers who are experts in biology education. The test was finalized with the feedback received from expert opinions. As a result of the analyses, it was seen that the four-tier SCDT was a reliable and valid.

Percentages of participants' scientific knowledge, lack of knowledge and misconceptions based on test items and subscales

The percentages of scientific knowledge, lack of knowledge and misconceptions were calculated based on factors and test items of the four-tier SCDT and were given in Table 6.

Table 6. *Percentages of participants' scientific knowledge, lack of knowledge and misconceptions*

Factor	Test Items	Scientific Knowledge	Lack of Knowledge	Misconception
Factor 1 Physiology of the Seed	Q9	%7.33	%58.92	%27.63
	Q7	%10.27	%63.08	%16.38
	Q3	%3.18	%64.79	%10.51
	Q11	%17.11	%70.66	%4.16
	Q6	%3.42	%66.99	%20.05
	Average	**%8.26**	**%64.89**	**%15.75**
Factor 2 Seed and Reproduction Relationship	Q2	%5.87	%55.99	%26.65
	Q8	%5.62	%66.75	%13.45
	Q5	%5.13	%65.53	%16.63
	Average	**%5.54**	**%62.76**	**%18.91**
Factor 3 Seed and Classification Relationship	Q1	%12.96	%70.42	%8.56
	Q10	%11.00	%70.42	%13.45
	Q4	%10.27	%71.64	%11.25
	Average	**%11.41**	**%70.83**	**%11.09**
	Overall Average	**%8.40**	**%66.16**	**%15.25**

When Table 6 was analysed, it was seen that the average percentage of participants' scientific knowledge for the questions in the first factor was 8.26%, the percentage of lack of knowledge was 64.89% and the percentage of misconceptions was 15.75%. For the questions in the second factor, the average percentage of participants' scientific knowledge was 5.54%, the percentage of lack of knowledge was 62.76% and the percentage of misconceptions was 18.91%. Finally, for the questions in the third factor, the participants' average percentage of scientific knowledge was 11.41%, the percentage of lack of knowledge was 70.83% and the percentage of misconceptions was 11.09%. When evaluated on a factor basis, it was determined that the highest average of scientific knowledge was in the third factor. The highest average of lack of knowledge was in the third factor and the highest average of misconceptions was in the second factor. When evaluated in general, it was seen that the average percentage of scientific knowledge was 8.40%, the percentage of lack of knowledge was 66.16% and the percentage of misconceptions was 15.25%. This showed that approximately one fourth of the 12th grade secondary school students had misconceptions about seeds.

All validity and reliability analyses were repeated after each question and the values presented in all analysis tables were given for the final data. For SCDT, all analyses of which were completed, the question numbers were revised and the questions were listed homogeneously. New item numbers were used in all tables where analysis results were presented in order to ensure standardisation and clarity. In the last case, the question numbers included in factors are as follows; Factor 1, Q1, Q3, Q6, Q7, Q9, Q11; Factor 2, Q2, Q5, Q8; Factor 3, Q1, Q4, Q10.

Findings regarding misconceptions

The misconception rates given in Table 6 were obtained from each question separately and combined under factors and given as averages. However, at this stage, the total rates of misconceptions were calculated for each of the misconceptions about the seed, which were created by combining some questions and given in Table 2. In this context, the percentages showing how many 12th grade secondary school students have the 30 misconceptions that showing up during the development of SCDT within the scope of the study are given in Table 7. In Figure 2, the percentage values of these misconceptions are shown graphically.

Table 7. *Percentages of misconceptions in SCDT*

***N*=409**	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**
Mean	8	16	10	61	5	14	16	10	13	9
%	2.0	3.9	2.4	14.9	1.2	3.4	3.9	2.4	3.2	2.2
***N*=409**	**M11**	**M12**	**M13**	**M14**	**M15**	**M16**	**M17**	**M18**	**M19**	**M20**
Mean	29	7	19	51	8	26	18	22	24	4
%	7.1	1.7	4.6	12.5	2.0	6.4	4.4	5.4	5.9	1.0
***N*=409**	**M21**	**M22**	**M23**	**M24**	**M25**	**M26**	**M27**	**M28**	**M29**	**M30**
Mean	5	54	27	29	21	10	5	3	16	6
%	1.2	13.2	6.6	7.1	5.1	2.4	1.2	0.7	3.9	1.5

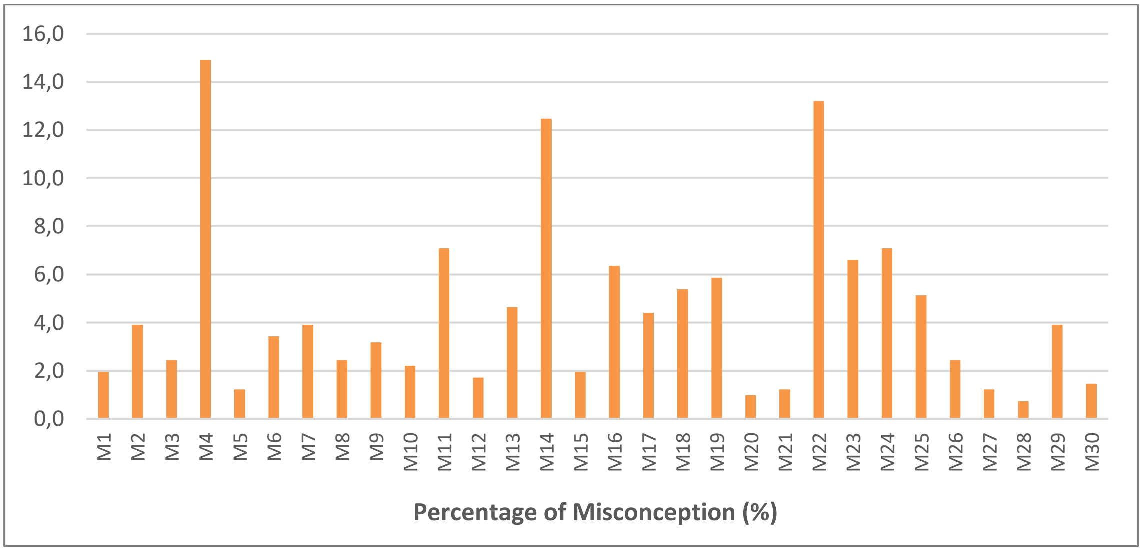

Figure 2. *Percentages of misconceptions of 12th grade secondary school students*

When Table 7 and Figure 2 were analysed, it was seen that more than 10% of 12th grade secondary school students had 3 misconceptions. These misconceptions included sexual and asexual reproduction of seed and photosynthesis in seed germination. These misconceptions are as follows:

• M4 (14.9%). The potato plant cannot reproduce by seeds because this plant is planted in the soil as a tuber; the tuber is not a seed.

• M14 (12.5%). The seed is a reproductive cell because the plant develops from this cell.

• M22 (13.2%). Sunlight is needed for photosynthesis during seed germination because the seed cannot survive in a light-free environment.

DISCUSSION

In this research, a four-tier SCDT was developed to determine 12th grade secondary school students' misconceptions about seeds. Factor-based values of students' scientific knowledge, lack of knowledge and misconception percentages about seed concept were calculated. As a result of these analyses, it was determined that the highest scientific knowledge average was under the "Seed and Classification Relationship" factor. It was determined that the lowest scientific knowledge average of the students' was under the " Seed and Reproduction Relationship" factor. When evaluated questions, it was understood that the highest scientific knowledge average was in the 11th question, and the lowest scientific knowledge average was in the 3rd question. It was determined that the highest lack of knowledge average was under the "Seed and Classification Relationship" factor. It was determined that the lowest lack of knowledge average was under the "Seed and Reproduction Relationship" factor. When evaluated on the question basis, it was seen that the highest lack of knowledge average was in the 4th question, and the lowest lack of knowledge average was in the 2nd question. It was determined that the students' highest misconception average was under the "Seed and Reproduction Relationship" factor, and that the lowest misconception average was under the "Seed and Classification Relationship" factor. When evaluated on the question basis, it was seen that the highest misconception average was in the 9th question, and the lowest misconception average was in the 11th question.

30 different misconceptions were found out with the developed four-tier SCDT. The results of this research it indicates that approximately one quarter the 12th grade secondary school students had misconceptions about seed, and the rate of three of the misconceptions was over 10%. It was observed that these misconceptions included the sexual and asexual reproduction of seeds and photosynthesis in seed germination. "Potato plants cannot reproduce by seeds because this plant is planted in the soil as a tube; a tuber is not a seed" (M4) was the most common misconception among students (14.9%). M4 is a misconception that appears only in the 2nd question (Table 2). The 2nd question is under the 2nd factor (Seed and Reproduction Relationship). It was understood that the students' highest misconception average was in the second factor. The average percentage of misconceptions in this category was 18.91%.

Another misconception frequently encountered by students (13.2%) was "Sunlight is needed for photosynthesis during seed germination because the seed cannot continue its vitality in a light-free environment" (M22). M22 is a misconception that only appears in the 9th question. The 9th question is under the 1st factor (Physiology of the Seed). When the factors were evaluated among themselves, it was understood that the average of the highest number of misconceptions was in the first factor after the second factor. The average percentage of misconceptions in this category is 15.75%. Additively M22, misconception "The seed is a reproductive cell because the plant develops from this cell" (M14) is also under this factor (12.5%). M14 is a misconception that only appears in the 6th question.

It is known that the subject of photosynthesis is a difficult subject for students (Marmaroti & Galanopoulou, 2006). Svandova (2014) determined, with the two-tier concept diagnostic test he developed for photosynthesis and plant respiration, that 6th, 7th, 8th and 9th grade students had many misconceptions such as plant respiration and photosynthesis are the same processes, photosynthesis occurs during the day and respiration occurs at night. Similarly, Uzunhasanoğlu et al. (2020) determined, with the two-tier concept diagnostic test they developed for general biology topics, that prospective biology teachers had the misconception that plants photosynthesize during the day and respire at night. In their study with a two-tier test on the subject of photosynthesis, Atchia et al. (2022) found that Secondary school Cambridge A level biology students had the misconception that photosynthesis occurs in the presence of light energy. With the two-tier concept diagnostic test he developed for the subject of photosynthesis, Urey (2018) determined that prospective science teachers had the misconception plants photosynthesise during the day and respire just at night. With the two-tier concept diagnostic test he developed for the growth and development of flowering plants, Lin (2004) found that 10th and 11th grade students had misconceptions such as "Seeds need sunlight during photosynthesis to produce energy for germination." In their study, Haslam and Treagust (1987) developed a two-tier test for secondary school students about photosynthesis and respiration in plants. They determined that students had important misconceptions like a "If there is no light energy at night, photosynthesis stops while respiration continues." regarding respiration and photosynthesis in plants. As can be seen from all these studies conducted by Svandova (2014), Uzunhasanoğlu et al. (2020), Atchia et al. (2022), Urey (2018), Lin (2004) and Haslam and Treagust (1987), even though they are at different age groups and grade levels, students have an important misconception that sunlight is absolutely necessary for photosynthesis. The misconception coded M22, which was determined to be held by the 12th grade secondary school students with the four-tier SCDT developed for the concept of seed in this study, that the seed cannot photosynthesize in the light-free environment, is similar to the results of all these studies. Considering the study of Haslam and Treagust (1987), which is the oldest of these studies, it is seen that students have still had the same misconceptions for 35 years, and therefore it is thought that no elimination or prevention studies have been carried out for these misconceptions. Teachers play the most important role here. They should know the literature well and prepare the lesson plan by knowing the existing misconceptions and use different teaching methods and techniques when necessary to prevent possible misconceptions.

Sesli and Kara (2012) determined, with the two-tier concept diagnostic test they developed for the subject of cell division and reproduction, that high school students had misconceptions such as "Plants cannot reproduce asexually because they have no gender", "Plants reproduce asexually while animals reproduce asexually", "Plants cannot reproduce asexually because they cannot move and develop reproductive organs". Similarly, with the two-tier concept diagnostic test they developed for the subject of cell division and reproduction, Arslan et al. (2015) determined that 10th grade students had misconceptions such as "Non-flowering plants reproduce by asexual reproduction and flowering plants reproduce by sexual reproduction" and "Plants reproduce only by asexual reproduction". The misconceptions coded M4 and M14 that the potato does not have a seed because it reproduces by asexual reproduction and that the seed is a reproductive cell because the plant develops from this cell, which were determined to be held by 12th grade secondary school Students with the four-tier SCDT developed for the concept of seed in this study, are similar to the results of this study. Therefore, it was observed that students generally had misconceptions about reproduction in seeds and could not fully understand sexual and asexual reproduction in plants.

When the 9th, 10th, 11th and 12th grade biology curriculum is examined, the distinction between seedless and seed plants in the plant kingdom is mentioned in the "World of Living Things" unit in the 9th grade curriculum. In the 10th grade curriculum, the concept of seed is included within the subject of sexual reproduction in plants in the "Cell Divisions" unit. In the 12th grade curriculum, the concept of seed is covered in detail within the subject of reproduction in plants in the "Plant Biology" unit. Therefore, students are required to have basic knowledge on subjects involving the concept of seed. According to the analysis results of this study, it was seen that the percentage of misconceptions of 12th grade students about seed was quite high. This result revealed the importance of transforming the knowledge acquired by students until 12th grade into permanent and meaningful learning in their mental structures and preventing possible misconceptions.

The four-tier SCDT, which was developed within the scope of this research and whose validity and reliability analyses were performed, aims to determine the misconceptions of 12th grade secondary school students about the concept of seed. It is thought that this test will contribute to the literature and will be used by teachers and researchers in detecting misconceptions about seeds on different sample groups, and therefore will be a pioneer in similar studies. In addition, various studies should be clearing misconceptions determined in this research.

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Author contributions

This article was produced from the first author's master's thesis. The second author was the second author's master's thesis advisor and contributed to all processes of the research. In addition, the third author made great contributions in analysing the data and reporting and discussing the results with the support of the literature. For this reason, this study, in which all authors worked together, was organized with three authors. All authors contributed to the concept and design of the study. All authors read and approved the final manuscript.

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