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A Four-Tier Diagnostic Test to Determine Pre-Service Science Teacher's Misconception About Solution

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Abstract

Misconceptions are one of the most serious obstacles to the effective and efficient conduct of science education. Therefore, it is very important to determine misconceptions. In the study, a misconception diagnosis test was developed for the topic of solutions. The validity and reliability studies of the misconception diagnostic test developed by the researchers were carried out with 203 pre-service science teachers. The analyses indicate that the developed diagnostic test satisfies the validity and reliability criteria essential for identifying misconceptions within the group of pre-service science teachers concerning the topic of solution. The developed test consists of eight questions in four stages. The test showed a two-factor structure. The reliability coefficient of the test was calculated as KR-20, .704 for scientific knowledge and KR-20, .741 for misconceptions. Researchers believe that the conceptual misconception diagnosis test they have developed will serve as a guide for efforts to identify and eliminate existing misconceptions about solutions in prospective science teacher candidates. A four-stage misconception diagnostic test for the subject of solutions was not found in the literature. In this respect, the study is considered to be unique and powerful.

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Introduction

Science is a complex structure that includes many disciplines. One of these disciplines is chemistry. Chemical science is a science closely interacting with our daily life. Many products we use in our daily lives, many information, problems or problems we encounter include concepts related to chemistry science. The fact that these concepts related to chemical science are highly abstract makes it difficult for individuals to concretise these concepts in their own mental processes (Gilbert, 2006). The subject of solutions within the scope of chemistry is one of the subjects closely related to daily life. The first meeting of the concept of solution with students in the educational environment takes place in the 7th grade of primary education within the scope of science curriculum. The solution subject is one of the basic subjects of chemistry. The knowledge of the subject of solutions is the basis of many learnings that individuals will perform throughout their lives, in their daily lives and in education and training environments related to science. For this reason, learning the concepts related to this subject correctly and completely is important for future learning (Demirba et al., 2011).

Misconceptions are the biggest and most serious obstacle for all educational fields including science education. In order for deep and meaningful learning to occur in individuals, concepts must be learnt completely and correctly. Concepts that are not learnt correctly cause individuals to be unable to make sense of their learning in a scientific way and to establish correct relationships between scientific knowledge (Iwuanyanwu, 2019; Mataka & Taibu, 2020). For this reason, misconceptions are one of the issues that educators of science and other fields have paid serious attention to in recent years. Individuals' understanding of concepts is of great importance for science educators for the same reason. Information that is accepted as scientific knowledge by individuals but conflicting with scientific facts is referred to as a misconception (Allen, 2014; Eshach et al., 2018; Soeharto et al., 2019; Vosniadou, 2020). When reviewing the literature, numerous studies are found which showing that students have misconceptions about chemistry subjects (Abraham, et al., 1994; Camacho & Good, 1989; Ebenezer & Ericson, 1996; Garnett & Treagust, 1992; Pardo & Solaz-Patolez, 1995; Yasa & Kocak, 2022). Subjects containing abstract concepts are generally difficult to learn by students. The fact that the concepts contained in chemistry subjects are generally abstract concepts causes misconceptions in chemistry subjects. The fact that the academic language used in chemistry is far from everyday language and contains detailed calculations causes these subjects to be difficult to learn and contain misconceptions (Carter & Brickhouse, 1989; Üce & Ceylan, 2019; Veiga, Pereirave & Maskill, 1989). The subject of solutions is one of the subjects in which students have misconceptions (Blanco & Prieto, 1997; Demirbaş et al., 2011; Erdem et al., 2004; Friedler et al., 1985; Gabel & Samuel, 1987; Smith & Metz, 1996).

The main goal of this study was to create a measurement tool designed to identify misconceptions held by pre-service science teachers concerning the subject of solutions. In the study, a four-tier misconception diagnosis test was used as a data collection tool. The data collection instrument was created by the researchers within the scope of the study. Four-tier misconception diagnostic test prepared for the subject of solutions was not found in the literature. In this respect, the study is an original and powerful study. The misconceptions determined by the test developed by the researchers can reveal at which point of the subject of solutions students have unscientific beliefs. In addition, the determination of misconceptions will guide the improvement studies to be carried out to correct these misconceptions.

Method

Research Design

This study, which purposes to develop an assessment tool to designate the misconceptions of pre-service science teachers about the subject of solutions, was modeled with quantitative research method. The study employed the survey method, a quantitative research approach. The survey design is a quantitative study carried out on the whole universe or a group formed from the universe in order to reach an opinion and judgment in general terms about a universe shaped by a large number of elements. In studies conducted with the survey design, the current status of the universe, trends or values of the universe can be revealed (Creswell, 2017; Karasar, 2005).

Study Group

The research includes a study group comprising 203 pre-service science teachers. The study group consisted of pre-service science teachers from each grade level continuing their undergraduate education in the science teaching department of a state university in Turkey. The study data were gathered in the spring semester of 2022-2023 academic year. The study group was selected through the convenient sampling method. Convenience sampling refers to the process of collecting data from a research population that the researcher can reach. Basically, it can be defined as determining and using a sample that the researcher can easily reach (Koerber & McMichael, 2008; Rahi, 2017). The graph showing the number distribution of pre-service science teachers according to grade level is presented in Figure 1.

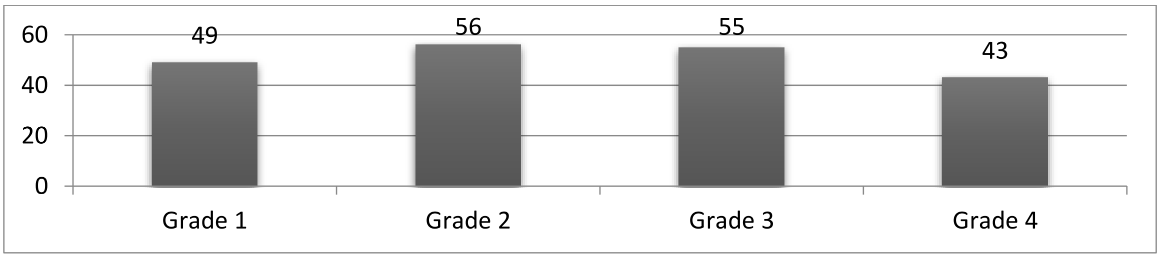

Figure 1. Pre-Service Science Teachers' Grade Levels

Data Collection Tool and Process

The "Solutions Four-Tier Misconception Diagnosis Test" used in the study was developed by the researchers. The developed solutions four-tier misconception diagnostic test consists of eight questions. During the test development process, the researchers benefited from literature review on misconceptions and instructor observations. During the question preparation process, firstly, a comprehensive literature study on the subject was conducted and misconceptions in the literature on solutions were determined. Then, a pool of items was formed by blending the misconceptions identified by the instructors in the course and laboratory applications and the misconceptions in the literature. The statements in the item pool were analysed by the researchers. As a result of the examination of the item pool, eight questions that harbor possible misconceptions were decided upon. The eight questions were formed as multiple-choice and turned into a four-tier diagnostic test with the addition of reason and confidence steps. The developed draft test was sent to three field experts and expert opinions were obtained. Two of the experts whose opinions were requested were science educators and one of them was a chemistry educator, and they were field experts who had studies on misconceptions. The test took its final form by making arrangements with feedback from the expert opinions.

Data Analysis

Four-tier misconception diagnostic tests do not only identify misconceptions. These tests can also detect scientific knowledge, false negatives, false positives and lack of knowledge. During the calculations, correct answers are coded as “1” and incorrect answers as “0” for all stages. In confidence levels, statements expressing confidence are coded as “1” and statements expressing uncertainty are coded as “0”. The coding and findings of the four-tier misconception diagnostic tests are presented in Table 1.

Table 1. Coding of Four-Tier Misconception Diagnostic Tests and Possible Detections

First Tier	Second Tier	Third Tier	Fourth Tier	Coding	Final Decision
True	Sure	True	Sure	1-1-1-1	Scientific Knowledge
True	Sure	False	Sure	1-1-0-1	False Positive
False	Sure	True	Sure	0-1-1-1	False Negative
False	Sure	False	Sure	0-1-0-1	Misconception
True	Sure	True	Not Sure	1-1-1-0	LK 1
True	Not Sure	True	Sure	1-0-1-1	LK 2
True	Not Sure	True	Not Sure	1-0-1-0	LK 3
True	Sure	False	Not Sure	1-1-0-0	LK 4
True	Not Sure	False	Sure	1-0-0-1	LK 5
True	Not Sure	False	Not Sure	1-0-0-0	LK 6

False	Sure	True	Not Sure	0-1-1-0	LK 7
False	Not Sure	True	Sure	0-0-1-1	LK 8
False	Not Sure	True	Not Sure	0-0-1-0	LK 9
False	Sure	False	Not Sure	0-1-0-0	LK 10
False	Not Sure	False	Sure	0-0-0-1	LK 11
False	Not Sure	False	Not Sure	1-0-0-0	LK 12

*LK; Lack of Knowledge

The four-tier misconception diagnostic tests can detect a total of 16 different situations, including 12 different lack of knowledge statements. When interpreting the answers given by the participants to the test; if the person answered the first and third steps correctly and is sure of his/her answers, it is expressed as scientific knowledge; if he/she answered the first and third steps incorrectly and is sure of his/her answers, it is expressed as misconception. If the participant answered correctly in the first stage and incorrectly in the third stage and is sure of his/her answers, it is defined as false positive, and if the participant answered incorrectly in the first stage and correctly in the third stage, it is defined as false negative. When Table 1 is examined, it is noteworthy that there is uncertainty in at least one of the confidence steps while determining the types of lack of knowledge. If the learner is not sure of his/her answer (regardless of whether the answer is correct or incorrect), this is interpreted as a lack of knowledge. The finalized Solutions Four-tier Misconception Diagnosis Test was checked in terms of language, comprehensibility and fluency by having a pre-service science teacher from each grade level read the test after the adjustments made in line with the expert opinions.

Before the main application, a pilot study was conducted by applying the test to a group of pre-service science teachers who were not included in the study group. A group of forty eight pre-service teachers from each grade level was selected for the pilot study. The reliability coefficient was calculated after the pilot study. Both reliability coefficients calculated for the four-stage misconception diagnostic tests (KR-20 calculated for misconception scores (.706) and KR-20 calculated for scientific knowledge scores (.689) were within the appropriate range. After the pilot study, 203 pre-service science teachers were recruited for the main application. The validity and reliability studies of the test were carried out with the data obtained.

Results

Test Reliability Analysis

In the process of reliability analysis of four-tier misconception diagnostic tests, two different reliability coefficients are calculated. These coefficients: the reliability coefficient computed for misconception scores and the reliability coefficient computed for scientific knowledge scores within the same sample.

First Type Reliability: Scientific Knowledge Reliability Coefficient

The first reliability coefficient of the solutions misconception diagnostic test is computed based on the scientific knowledge score derived from instances where respondents answered the test questions correctly and expressed confidence in their responses. In fact, it is the reliability coefficient calculated over the score obtained by coding the participant responses as 1-1-1-1. The first reliability coefficient of the solutions misconception diagnostic test was determined as .704 through KR-20 analysis.

Second Type Reliability: Misconception Reliability Coefficient

The second type reliability coefficient of the solutions misconception diagnostic test is computed based on the misconception score derived from instances where respondents answered the test questions incorrectly but were confident in their responses. When calculating this reliability coefficient, the score obtained by coding the participant responses as 0-1-0-1 is taken as basis. The second type reliability coefficient of the solutions misconception diagnostic test was determined as .741 through KR-20 analysis.

When the literature is reviewed, it is seen that the reliability coefficient calculated at .05 and above in tests where the number of items is less than 15 is found to be satisfactory. Both calculated values indicate that the test is a reliable measurement tool (KR-20 > 0.7) (Mc Alpine, 2002; Vegada *et al.,* 2014).

Validity Analysis of the Test

The validity of the four-tier misconception diagnostic tests is assessed through data obtained using four distinct methods (Taban & Kiray, 2021).

Validity 1: Expert Opinion

In the process of preparing the questions and creating the item pool, expert opinions were obtained from two science educators for the organization of the open-ended questions asked to the pre-service teachers. After the question preparation and test development phase was completed, the pilot test was shared with two science education experts and one chemistry education expert working as faculty members in different universities. Expert opinions were received and necessary corrections were made.

Validity 2: False Positive and False Negative

One of the conditions for ensuring validity in the four-tier diagnostic tests is the calculation of the percentages of positive false and negative false total scores below 10% (Hestenes & Halloun, 1995). In the analyses conducted using data collected from pre-service teachers as part of the study, the average false positives were computed as 9.79%, and the average false negatives were calculated as 3.69%. Both figures fall below the 10% threshold.

Validity 3: Factor Analysis

Factor analysis was conducted to assess the construct validity of the test designed to identify misconceptions among pre-service science teachers regarding the topic of solutions. In this step, Exploratory Factor Analysis was applied to the developed test. The KMO value obtained as a result of the analyses shows that the developed test is suitable for factor analysis (KMO; .757). The obtained KMO value shows that the sample size is sufficient. When the literature is examined, it is seen that the KMO value is considered appropriate for samples of this size when it is calculated as 0.7 and above (Guttman, 1954; Kaiser, 1970). Bartlett's Test of Sphericity, another value for factor analysis, was found to be significant ($p<.05$). This value supports that the data are suitable for factor analysis (Shrestha, 2021). With the exploratory factor analysis, the test showed two sub-dimensional structures. The eigenvalue criterion was taken as a basis in determining the sub-dimensions, i.e. factors (Pallant, 2010; Verma, 2013). Two factors with an eigenvalue value of 1 and above were determined as sub-dimensions. The analysis shows that these two factors explain 54.55% of the total variance.

Based on the findings of the exploratory factor analysis, the developed test has two sub-dimensional structures. The first sub-dimension is the solubility sub-dimension including questions 1, 3, 6 and 8; the second sub-dimension is the type of solvent and solute sub-dimension including questions 2, 4, 5 and 7. The findings from the exploratory factor analysis are outlined in Table 2.

Table 2. Results of Exploratory Factor Analysis

Sub Dimensions Items	**Solubility**	**Type of Solvent and Solute**
1	.700	
3	.596	
6	.550	
8	.688	
2		.835
4		.760
5		.485
7		.783

When Table 2 is examined, it is seen that factor 1 is labeled with the title of solubility. The items within the scope of factor 1 are items 1, 3, 6 and 8. These items have a correlation of 0.70, 0.59, 0.55 and 0.68 with factor 1, respectively. Factor 2 is named as the type of solvent and solute. The items within the scope of this factor are items 2, 4, 5, and 7. The correlations of these items with factor 2 are 0.83, 0.76, 0.48 and 0.78.

Validity 4: Correlation Between Science Teacher Candidates' Confidence Scores and Correct Answer Scores

In the research, three distinct correlation coefficients were computed to investigate the relationship between the scores of correct answers and the confidence levels of pre-service teachers. These;

1. Correlation coefficient for the first tier and second tier (associated with the first confidence score).
2. Correlation coefficient for the third tier and fourth tier (associated with second confidence score)
3. Correlation coefficient between the first and third tiers and the second and fourth tiers (both confidence score). The results derived from the analysis are showcased in Table 3.

Table 3. Correlation Coefficient of Solutions Misconception Diagnostic Test

Tier Scores	**Pearson Correlation**	**p**
Confidence Score (First)	.293	.000
Second Confidence Score (Second)	.274	.000
Confidence Score (Both)	.331	.000

The first confidence score was calculated as .293. This coefficient score indicates that there is a meaningful positive relationship between the answers given by the pre-service teachers to the first and second steps. The second confidence score was calculated as .274. This coefficient indicates that there is a meaningful positive correlation between the pre-service teachers' responses to the third and fourth step. The final correlation coefficient pertains to the correlation calculated based on the responses provided by pre-service teachers to the first and third steps with the second and fourth steps. This value was calculated as .331 and it indicates that there is a meaningful positive relationship between both confidence scores of pre-service teachers. Taban and Kıray (2021) noted that given the challenging nature of misconception tests, there should be a meaningful positive relationship between the mentioned steps, even if it is weak. Considering this criterion, it is evident that the validity criterion is satisfied. A sample question of the developed test is presented in Figure 2.

6.2. When a certain amount of a saturated solution is used, how does the concentration of the remaining solution change?
A) The concentration decreases
B) The concentration increases
C) The concentration does not change

6.2. Are you sure about your answer above?
A) Absolutely sure
B) I am sure
C) Not Sure
D) Absolutely Not Sure

6.3. Which of the following is your reason for selecting the above option?
A) If the amount of solvent decreases, the concentration decreases.
B) If the amount of solvent decreases and the solute precipitates, the concentration decreases.
C) Since the amount of solute per unit volume decreases, the concentration decreases.
D) Since the amount of solvent decreases, the amount of solute per unit volume increases, and the concentration increases.
E) Since both the solvent and the solute decrease in the same proportion, the concentration does not change.
F) Since the amount of solvent decreases while the amount of solute remains the same, the concentration does not change.
G) Other (Please specify if you have another reason)

6.4. Are you sure about your answer above?
A) Absolutely sure
B) I am sure
C) Not Sure
D) Absolutely Not Sure

Figure 2. Example Question

Misconceptions, Scientific Knowledge, False Positive and False Negative Rates of Pre-Service Science Teachers About the Subject of Solutions

The percentages of pre-service science teachers in the categories of scientific knowledge, misconception, false positive, false negative and lack of knowledge about the subject of solutions are presented in Table 4 on the basis of question and factor.

Table 4. Classification and Percentage Ratios of Pre-Srvice Teachers' Answers by Question and Factor

	Factor 1; Solubility					**Factor 2; Type of Solvent and Solute**				
Test Items (%)	1	3	6	8	X	2	4	5	7	X
Scientific Knowledge	40.88	61.08	50.24	54.18	51.60	53.20	37.93	32.01	29.55	38.17
False Positive	9.85	6.40	15.27	7.38	9.72	4.92	13.30	0.98	20.19	9.85
False negative	2.46	0.49	0.98	20.19	6.03	0	4.43	0.98	0	1.35
Misconcep-tion	14.28	16.74	11.82	13.30	14.03	2.46	6.89	13.30	7.88	7.63
Lack of Knowledge	32.53	15.29	21.69	4,95	18.61	39.42	62.55	52,73	42.38	49.27

When Table 4 is analyzed, it is observed that the question with the highest percentage of scientific knowledge (61.08%) is the third question and the question with the lowest percentage of scientific knowledge (29.55%) is the seventh question. When the false positive percentages of the pre-service science teachers were analyzed, it was seen that the question with the highest percentage of false reasoned truths was the seventh question (20.19%) and the question with the lowest percentage of false reasoned truths was the fifth question (0.98%). When the percentage of false negative, which we call as errors with correct reasons, is analyzed, it is seen that the highest percentage of false negative is in the eighth question, while the lowest percentage of false negative is in the second (0%) and seventh (0%) questions. While answering the eighth question, 20.19% of the pre-service teachers made the right choice at the reason step and the wrong choice at the content step. Another finding obtained when Table 3 is analyzed is the misconceptions of pre-service teachers about the subject of solutions. When the table is analyzed, it is seen that the question with the highest rate of misconceptions is the third question (16.74%) and the question with the least misconceptions is the second question (2.46%). Another finding obtained as a result of the analysis is the percentage of lack of knowledge of the pre-service science teachers. According to the results of the analysis, 62.55% of the pre-service science teachers stated that they were not sure about at least one of the confidence step answers while answering the fourth question. The question in which pre-service science teachers had the least knowledge deficiency was the eighth question (4.95%).

Discussion and Conclusion

The aim of this study is to create a valid and reliable measurement instrument capable of identifying misconceptions among pre-service science teachers regarding solutions. In the course of the research, a four-tier misconception diagnosis test was specifically developed for this purpose. The developed misconception diagnosis test has two sub-dimensions as "solubility" and "type of solvent and solute". These two sub-dimensions of the misconception diagnostic test were reached by exploratory factor analysis. According to the findings of the exploratory factor analysis, the first, third, sixth and eighth items are the questions prepared within the scope of the first sub-dimension, solubility factor. The second, fourth, fifth and seventh questions belong to the second factor, solvent and solute type dimension. The findings obtained from the validity and reliability studies show that the diagnostic test developed has standards that can be used to identify misconceptions about the subject of solutions. For the reliability analysis of the test, KR-20 reliability coefficient was calculated on the basis of misconception and scientific knowledge scores and this coefficient was above .70 in both categories. Validity analyses were conducted through four steps, and the outcomes of all the analyses indicate that the test is a valid and reliable measurement tool.

Upon reviewing the misconception analyses, it is evident that pre-service science teachers harbor significant misconceptions (10% and above) related to the content of the first, third, sixth, eighth, and fifth questions. Similarly, when the lack of knowledge analyses are examined, it is seen that pre-service science teachers have notable (10% and above) lack of knowledge in all questions except the eighth question. According to the results of the analyses, over half of the pre-service teachers have lack of knowledge for the fourth and fifth question contents.

When the literature is examined, studies focusing on the determination of misconceptions about the subject of solutions are found. Although different methods and techniques were used to identify misconceptions in the studies, there was no study using a four-tier misconception diagnostic test. For example, Kalın and Arıkıl (2010) aimed to determine the misconceptions of university students in different departments about the subject of solutions by using the interview technique in addition to the open-ended questions they prepared in their study. Demirbaş et al. (2011) used open-ended questions to determine the misconceptions of pre-service science teachers about the subject of solutions. In addition to open-ended questions, the researchers also asked for the reason for the answer. Koray et al. (2003) developed a misconception test to determine high school students' misconceptions about solubility. The developed test consists of two parts: definition of the concept and application question. Bulut et al. (2021) determined the misconceptions of pre-service chemistry teachers about solutions and solubility through concept maps. Liu and Lesniak (2006) aimed to reveal high school students' misconceptions about the concept of dissolution and used semi-structured interview questions in the data collection process. Krause and Isaacs-Sodeye (2013) used a worksheet to reveal the misconceptions of university students from different departments about the concepts of solutions, solubility and saturation.

When the literature is examined, it is seen that misconceptions about solutions are tried to be determined by using different methods and techniques. However, there is no study in which four-tier diagnostic test was used to determine misconceptions about solutions. Four-tier diagnostic tests are very important in terms of presenting the reason for the individual's answer to the question about the concept. Misconceptions are serious problems that can cause wrong learning by affecting lifelong learning processes. In this context, it is very important to identify them. The test created in the context of this study was designed to identify the misconceptions held by pre-service science teachers regarding solutions.

Recommendations

It is considered that determining the misconceptions of pre-service teachers by using the developed test is important in terms of determining the focus in curriculum development studies. It is also thought that the test formulated as part of the study can be used as a pretest-posttest within the scope of an appropriate application plan by designing an experimental study and the elimination of misconceptions can be controlled.

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