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University students' scientific knowledge levels regarding chemical reaction arrows and electron arrows

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Abstract: This study investigated undergraduate students' recognition of chemical reaction arrows and electron arrows and their understanding of their functions. The research was conducted using a comparative research design. A four-tier diagnostic test for chemical reaction arrows and electron arrows was developed. 181 university students participated in the test development phase. The difficulty and discrimination indices of the test items were calculated. The reliability coefficient of the test was found to be 0.76. The four-tier diagnostic test was then administered to 174 university students to determine whether the participants' levels of scientific knowledge of chemical reaction arrows and electron arrows differed by gender, department and grade levels. The results showed that the university students had an inadequate level of scientific knowledge about chemical reaction arrows and electron arrows. It was found that more than half of the university students were deficient in all questions. It was also found that the level of scientific knowledge of the participants did not differ according to gender, but did differ according to grade level and department. These differences were in favour of fourth year students and against electrical and electronics engineering students.

Keywords: chemical reaction arrows; diagnostic test; electron arrows; university students.

INTRODUCTION

The arrow is known as "baan" or "teer" in Sanskrit, a language belonging to the Indo–Iranian branch of the Indo–European language family.[1] This word, which means curve, is used to describe the arc.[2] Arrows have been used in many fields for many years and continue to be used. One of the fields in which arrows are commonly used is chemistry. Arrows are the most basic and widely used symbols in chemistry. Arrows are among the symbols used in the early days of alchemy and

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chemistry. Arrows were used to represent processes such as purification, layering, and some substances. These arrows were removed from chemistry texts with the introduction of atomic symbols by Berzelius in 1814. Arrows regained their place in chemistry with the use of arrows to represent chemical reactions. Chemical reactions and equations are represented by arrows. Arrows are also used to show the movement of electrons. The use of arrows makes it possible to avoid countless sequences of words and sentences.

Lakshminarayanan classified the arrows used in chemistry as reaction arrows and electron arrows.[1] Chemical reaction arrows are used to describe the state or progress of the reaction, while electron arrows are used to show the movement of electrons. Chemical reaction arrows are chemical reaction arrow (right arrow, left arrow), balance arrows (dynamic balance arrows, balance arrows in favour of reactants/products), the upward arrow, the downward arrow, the retrosynthetic arrow, clockwise and anti-clockwise arrows, the reflux arrow, the wavy arrow, the rearrangement arrow, the dashed arrow, the broken arrow and the crossed arrow. Electron arrows are the curved or curled arrow, the fishhook arrow, the resonance arrow, the mid-hook arrow, the dipole moment arrow and electrons occupying an orbital.

Historical development of arrow symbols

The first chemical equation (primitive reaction diagram) was drawn by Jean Beguin in 1615.[1] Lavoisier was the first to propose a type of chemical equation, linking reactants and products with an equal sign, in describing the fermentation of sugar.[3,4]

A chemical reaction arrow is a straight arrow showing the direction of chemical change. The most common arrow used in chemical reaction formulae is the right arrow. This arrow is shown with a straight line and a double hook at the right end of the line. The direction of the hook indicates the direction of the reaction. It indicates that the reactants are changing into products. If the direction of the arrow is reversed, it means that the products are changing into reactants.

Equilibrium arrows were first introduced by J.H. van't Hoff in 1884 in his book *Etude de Dynamique Chemique.*[5] These arrows are used to show the reversible reaction. H. Marshall revised these arrows in 1902 and used half-hooked arrows showing opposite directions, which are widely used today.[6] Half-hooked opposite double arrows are used to represent dynamic equilibrium. In equilibrium arrows in favour of the reactants, the arrow towards the products is shorter and there are more reactants than products at equilibrium. For equilibrium arrows in favour of products, the arrow towards the reactants is shorter and there are more products than reactants at equilibrium.

Curved arrows are the most important and widely used electron arrows. These arrows were introduced by Sir Robert Robinson in 1922.[1] This arrow is used to write the reaction mechanism by showing the movement of the electron. Single-hook fishhook arrows are used to show the movement of a single electron.[7] The resonance arrow is a double-hooked straight arrow that shows the similarity of two equivalent structures of the same molecule. Although the concept of resonance was first used by Linus Pauling in 1928, Fritz Arndt was the first to mention the resonance arrow.[1] This arrow links two structures of the same molecule with different electron distribution patterns.

Related studies

The number of studies focusing on arrow symbols in the educational research literature was limited. Some of these studies were in the form of reviews explaining the historical development of arrow symbols.[1,8] Studies focusing on arrow symbols in chemistry education have generally been conducted in organic and inorganic chemistry. Electron arrows were the focus of these studies. These studies generally investigated the use of curved arrows in computer-based training.[9] In another study that focused on the curved arrows representing electron flow in the organic reaction mechanism, researchers investigated the impact of an online learning module (interactive videos and activities with feedback) on undergraduate students' learning and experience.[10] The results showed that students made significant learning gains on questions that required them to draw the products of a reaction.[10] The most common type of error found in the research was drawing an arrow from an atom or charge. Berg and Ghosh investigated the value of the mechanistic approach in inorganic chemistry and found that this approach led to a participatory learning model.[11] They also reported that the arrow-pushing method created a descriptive, fun, reasoning-based and participatory classroom environment. Another study focusing on organic mechanisms showed that new bouncing curved arrows for electrophilic addition reactions can be a powerful teaching tool.[12] Ruder *et al.* used a method to assess students' use of curved arrows in multiple choice questions. The method was found to provide a deeper conceptual understanding of organic reactions and mechanisms.[13] Ferguson investigated how they made sense of the arrow pushing formalism.[14] The research was carried out with 16 university students studying chemistry. The barriers to their understanding in solving problems were discussed. A recent study investigated the effects of using diagrammatic arrows in an animation of salt dissolution.[15]

Current study and research questions

The studies described above were generally carried out by chemistry students in organic chemistry classes and fell within the scope of the curved arrow. The valuable contributions of these studies to the field of chemistry education should not be overlooked. Science students will encounter some reaction and electron arrows at every stage of their school, university or postgraduate studies. Arrow symbols are an integral part of chemistry and contribute to its understanding. For this reason, it is important to assess students' knowledge of arrow symbols.

People often use diagrams to facilitate communication.[16] Arrow symbols are often used in these diagrams and are one of the components of these diagrams. Arrow symbols have no specific meaning except in context. Arrow symbols provide information about other elements that are shown around them or that can be inferred from the context.[16] Arrow symbols can have semantic roles such as labelling, indicating direction and indicating movement.[16] Arrow symbols are the most powerful pictorial devices used in chemistry.[1] The semantic role of arrow symbols used to represent reactions and the movement of electrons was to indicate direction and movement. It is important for undergraduate science students to know the name and function of these arrow symbols, which are used to determine the direction of reactions and the movement of electrons. Recognising reaction arrows and knowing their functions provides information about the direction of the reaction. Recognising electron arrows and knowing their functions gives information about the movement of electron. It contributes to the understanding of chemical reactions and reaction mechanisms by providing information about other elements that are shown around them or can be inferred from context.

Chemistry, one of the branches of science, is difficult for many students of different ages to learn, because it contains abstract concepts.[17] Chemistry is a branch of science that explains how macroscopic events occur at the particle level, using numbers and symbols.[18,19] As can be seen from the definition, chemistry includes macroscopic, microscopic and symbolic representations.[20] According to Johnstone, one of the reasons why chemistry is difficult for students is that it requires multidimensional thinking.[21] Understanding complex chemical processes requires making connections between the symbolic, microscopic and macroscopic levels.[22,23] This connection contributes to more permanent learning of chemistry topics and understanding of chemical principles.[24] The present study revealed the levels of scientific knowledge, misconceptions, positive/negative errors, lack of confidence and lack of knowledge regarding reaction arrows and electron arrows of undergraduate science students. In this respect, it is believed that the research will make a significant contribution to the relevant literature.

In order to understand a drawing containing arrow symbols, the reader must infer the semantic role of each arrow symbol. It may be easy for adults with sufficient experience in drawing communication to make such comments.[16] However, interpreting arrow symbols used in chemistry remains a problem for undergraduate science students. In addition, failure to learn basic principles in general chemistry makes it difficult to transfer this knowledge to courses such as organic chemistry.[14] Undergraduate science students will struggle with problems related to the correct use of curved or reaction mechanisms. In the current research, it is important to identify the level of scientific knowledge of undergraduate students and their lack of knowledge of arrow symbols. Chemical reactions and electrons are the fundamental topics of chemistry. In addition, understanding these topics ensures the understanding of other chemistry topics. Chemical reaction arrows and electron arrows are used in many topics in university chemistry. It is important for university students to recognise chemical reaction arrows and electron arrows and to understand their functions when learning chemistry topics. A chemical reaction has reactants and products. Chemical reactions are written in formulae. Chemical reaction arrows are used in formulae. The most common arrows used in chemical reactions are: right arrow, left arrow, balance arrow, dynamic balance arrow, balance arrow in favour of reactants/products, dashed arrow, crossed arrow and broken arrow. Electron arrows show the movement of electrons. The most commonly used electron arrows are: single-ended curved arrow (fishhook arrow), double-ended curved arrow (curved, curly) and resonance arrow. The aim of this research is to compare the level of scientific knowledge of university students about chemical reaction arrows and electron arrows. In this context, the research questions are presented below:

1) What was the validity and reliability evidence of the four-tier diagnostic test developed to determine university students' level of recognition of chemical reaction arrows and electron arrows and understanding of their functions?

2) What were the levels of scientific knowledge, misconceptions, positive/negative errors, lack of confidence and lack of knowledge of undergraduate science students about reactions and electron arrows?

3) Was there a difference between university students' levels of scientific knowledge regarding chemical reaction arrows and electron arrows according to gender?

4) Was there a difference between university students' levels of scientific knowledge regarding chemical reaction arrows and electron arrows according to department?

5) Was there a difference between university students' levels of scientific know-ledge regarding chemical reaction arrows and electron arrows according to grade level?

EXPERIMENTAL

Research design

A quantitative research method was used in the study. A comparative research design, one of the non-experimental quantitative research designs, was used in the research. It is preferred as the best option when experimental models cannot be used.[25] This design is a step forward from survey research. This design was preferred in the research to find out whether there were statistically significant differences between university students' levels of scientific knowledge of chemical reaction arrows and electron arrows according to gender, department and grade level. In a comparative design, the researcher conducts research in the natural environment. Cause-effect relationships are not sought in the results of such studies.

Sample

The research was carried out with university students. 181 students participated in test development phase. The test was then administered to another group of 174 students. Convenience sampling, a non-random sampling techniques, was used in the research. The participants were favoured due to their proximity to the researchers. Due to time and labour constraints, the sample was selected from easily accessible and convenient locations.[26] The participants were second, third and fourth year students who taken chemistry courses during their undergraduate education. They were studying in the departments of science teachers, molecular biology and genetics, mechanical engineering, civil engineering, electrical and electronics engineering and biotechnology. Mechanical, civil and electronics engineering students took four or five hours of chemistry per week (one or two hours were laboratory or practical) in the first semester of their undergraduate education. Pre-service science teachers took four hours of chemistry per week (two hours were practical) in the first, second and third semesters of their undergraduate education. Biotechnology students took three or five hours of chemistry per week (two hours were practical) during the first six semesters of their undergraduate education. Molecular biology and genetics students took three or five or six hours of chemistry per week (two or three hours were practical) during the first six semesters of their undergraduate education. While students from the Faculty of Engineering were taught only general chemistry, students from the Faculty of Education (pre-service science teachers) were taught general, organic and analytical chemistry. The science faculty students (biotechnology and molecular biology and genetics) were taught general chemistry, organic chemistry and biochemistry. Participants were placed in their undergraduate programmes based on numerical scores. In order to be admitted to these departments in education and engineering faculties in Turkey, it was necessary to be in the top three hundred thousand in terms of numerical score in the university entrance exams. In the pilot study, the majority of participants (82.8 %) were studying at a state university (A university) in the Western Black Sea region. In addition, a small number of students studying at different universities in Turkey also participated in the pilot study (as online). This provided the missing sample for the validity and reliability stages of the test. For the main study, all participants studied at another state university (B university) in the Western Black Sea region. Participation in the research was completely voluntary. Ethics Committee approval was obtained and all ethical standards were followed during the research. The sample group is detailed in Table I.

Data collection tools

In recent years, two-, three- and four-tier diagnostic tests have emerged. The first tier of two-tier tests is content and the second tier is reasoning. Two-tier tests could not distinguish whether the student had a lack of knowledge or a misconception.[28] A confidence tier was added to the two-tier tests to create three-tier diagnostic tests. In three-tier tests, it is not known whether the student is confident about the content in the first tier, the reason in the second tier, or both answers. Therefore, a four-tier diagnostic test was developed and used in this study. We developed and used the Chemical Reaction Arrows and Electron Arrows diagnostic test as a data collection tool. The diagnostic test was constructed by the researchers and its validity and reliability were tested. The test included nine (9) chemical reaction arrows and three (3) electron arrows, which are commonly used in chemical reactions and the movement of electrons. This test was designed in four tiers and the questions were open-ended.

The first tier of this test was the content stage and it was the stage where the participants' knowledge was described. In this stage, the participants were presented with pictures of the arrows and it was determined whether they correctly named the chemical reaction arrows and electron arrows. The third tier was the reasoning stage and included the reason for the answer given in the first tier. This stage determined the participants' level of understanding of the functions of the chemical reactions arrows and electron arrows. In the second and fourth tiers, participants were asked whether they were confident of their answers in the content and reason tiers respectively.[27] The diagnostic tests for chemical reaction arrows and electron arrows are presented in Appendix-1 of the Supplementary material to this paper.

TABLE I. The sample of the research

Sample		Pilot study (test development)		Main study	
		Frequency	%	Frequency	%
Gender	Female	125	69.0	75	43.1
	Male	56	31.0	99	56.9
	Total	181	100	174	100
Grade level	Sophomore	81	44.7	74	42.5
	Third grade student	48	26.5	65	37.4
	Fourth grade student	50	27.6	35	20.1
	Unspecified	2	1.2	–	–
	Total	181	100	174	100
Department	Science teacher	59	32.6	56	32.2
	Molecular biology and genetics	57	31.5	–	–
	Mechanical engineering	23	12.7	41	23.5
	Civil engineering	4	2.2	29	16.7
	Electrical-electronics engineering	2	1.1	48	27.6
	Biotechnology	29	16.0	–	–
	Other	7	3.9	–	–
	Total	181	100	174	100
University	A university	150	82.8	–	–
	B university	16	8.9	174	100
	Other	15	8.3	–	–
	Total	181	100	–	100

Data analysis

The first and third tier of the test contained short-answer and open-ended questions. The criteria used to analyse the two-tiers of open-ended questions were used to score the test.[29] Correct reasoning (third tier) was worth 2 points and correct content (a first tier) was worth 1 point. Confidence tiers were not included in the scoring and were used to determine the level of scientific knowledge of the participants. We conducted validity and reliability analyses of the test using data from the pilot study. For this purpose, the difficulty and discrimination indices of each test question were calculated. The reliability coefficient of the test was calculated using the KR-20 formula. These calculations followed the item analysis steps applied to short-answer and open-ended questions.[30] Pilot study data were analysed using Excel.

SPSS 22 was used for the analysis of the main study. Normality of data was checked for each group. First, the mode, median and arithmetic mean of the groups were examined and it was found that the values were not close to each other. The kurtosis and skewness values for each group were not in the range of –1 and +1. As the number of participants was more than 50, the results of the Kolmogorov-Smirnov test were examined and it was found that the *p*-values were less than 0.05. The histogram graphs of the data were not in the form of a symmetrical curve. Therefore, non-parametric tests were performed on the main study data. The Mann-Whitney U test was used to compare the means of two groups, and the Kruskal-Wallis test was used to compare the means of more than two groups.

In this study it was determined whether the students had scientific knowledge, misconceptions, positive errors, negative errors, lack of confidence and lack of knowledge. For this purpose, decisions were made about the questions from the participants' responses to the four--tier diagnostic test according to the criteria in Table II.[31,32] The second and fourth tiers of the four-tier tests were the confidence tier. The confidence level of three or four-tier diagnostic tests should be constructed using *Likert*-type[33] or binary logic.[34] Students must be confident in their answers in order to avoid misconceptions.[35] The binary confidence tier was preferred in the current research. If the student answered the first and third tiers correctly and was confident in his/her answer for the second and fourth tiers, it meant that the student had scientific knowledge. If the student answered the first and third tiers incorrectly and was confident about the second and fourth tiers, the student had a misconception. If the student was confident in his/her answers and answered the first tier of the test correctly but the reason was wrong, he/she had a positive false. If the student was confident in his/her answers and answered the third tier of the test correctly but the first tier was wrong, he/she had a negative false. If the student's answers are correct but he/she is not confident about at least one tier of his/her answer, there is a lack of confidence. If a student is unconfident in at least one tier of their answers and at least one tier of their answer is incorrect, there is a lack of knowledge.

TABLE II. Comparison of decisions for all possibilities in the four-tier test

Arrow name	The state of being confident	Function	The state of being confident	Decision of the question
True	Confident	True	Confident	Scientific knowledge
True	Confident	False	Confident	M-Positive false
False	Confident	True	Confident	M-Negative false
False	Confident	False	Confident	Misconception
True	Confident	True	Not Confident	Lack of confident
True	Not confident	True	Confident	Lack of confident
True	Not confident	True	Not confident	Lack of confident
True	Confident	False	Not Confident	Lack of knowledge
True	Not confident	False	Confident	Lack of knowledge
True	Not confident	False	Not confident	Lack of knowledge
False	Confident	True	Not Confident	Lack of knowledge
False	Not confident	True	Confident	Lack of knowledge
False	Not confident	True	Not confident	Lack of knowledge
False	Confident	False	Not Confident	Lack of knowledge
False	Not confident	False	Confident	Lack of knowledge
False	Not confident	False	Not confident	Lack of knowledge

RESULTS

Findings for the first research question

The difficulty and discrimination indices of the test items were calculated from the test scores of 181 university students. There were 50 participants in each of the lower and upper groups. The difficulty and discrimination indices of each question are shown in Table III. The difficulty indices of the 12 questions ranged from 0.18 to 0.40. The discrimination indices were between 0.36 and 0.67. The average difficulty index of the test was 0.28 and the average discrimination index was 0.52. According to these results it can be said that the developed diagnostic test is a difficult test for university students. The reliability coefficient of the test was determined to be 0.76 using the KR-20 formula.

TABLE III. Item analysis

Question	Difficulty index	Discrimination index
1	0.32	0.51
2	0.26	0.45
3	0.40	0.61
4	0.36	0.64
5	0.18	0.37
6	0.18	0.36
7	0.25	0.49
8	0.35	0.67
9	0.31	0.61
10	0.32	0.63
11	0.24	0.48
12	0.20	0.41
Mean	0.28	0.52

Descriptive findings

After ensuring the validity and reliability, the diagnostic test was administered to 174 participants. There were 12 questions in the test and each question had a maximum of three points and a total of 36 points could be obtained from the test. It was found that the minimum score obtained from the test was 0 and the maximum score was 27. The average score of the test was 6.72 (see Table IV). It was found that the easiest question of the test was the second question (mean = 1.20) and the most difficult question was the seventh question (mean = 0.10). It was found that the average score obtained from the first two questions of the test was above one, while the average score obtained from the other questions was below one.

TABLE IV. Descriptive findings; *SD* = standard deviation

Question	Mean	*SD*
1	1.18	1.04
2	1.20	1.04
3	0.91	1.12
4	0.95	1.30
5	0.14	0.41
6	0.14	0.41
7	0.10	0.47

TABLE IV. Continued

Question	Mean	*SD*
8	0.29	0.72
9	0.27	0.67
10	0.46	0.75
11	0.18	0.69
12	0.83	1.07
Total	6.72	5.60

Findings for the second research question

Participants' understanding of chemical reaction arrows and electron arrows was grouped and presented in Table V. The percentage of participants with scientific knowledge ranged from 0.5 to 17.2 %. Lack of confidence was highest in the third (8.0 %) and fourth (8.6 %) questions. The rate of students with misconceptions was less than 10 % in all questions. Students had the most positive false (17.8 %) in the first question and the most negative false (9.1 %) in the twelfth question. More than half of the university students had lack of knowledge in all questions.

TABLE V. Grouping participants' understanding of chemical reactions and electron arrows; SK = scientific knowledge; LC = lack of confident; M = misconception; PF = positive false; NF = negative false; LK = lack of knowledge; *f* = frequency

Question	SK		LC		M		PF		NF		LK	
	f	%	*f*	%	*f*	%	*f*	%	*f*	%	*f*	%
1	30	17.2	5	2.8	10	5.7	31	17.8	3	1.7	95	54.5
2	30	17.2	5	2.8	8	4.5	30	17.2	4	2.2	97	55.7
3	18	10.3	14	8.0	16	9.1	12	6.8	3	1.7	111	63.7
4	30	17.2	15	8.6	12	6.8	3	1.7	2	1.1	112	64.3
5	1	0.5	0	0	4	2.2	4	2.2	0	0	165	94.8
6	1	0.5	0	0	5	2.8	3	1.7	0	0	165	94.8
7	3	1.7	0	0	12	6.8	0	0	1	0.5	158	90.8
8	7	4.0	1	0.5	7	4.0	1	0.5	1	0.5	157	90.2
9	6	3.4	0	0	7	4.0	1	0.5	2	1.1	158	90.8
10	5	2.8	4	2.2	2	1.1	4	2.2	0	0	159	91.3
11	6	3.4	2	1.1	5	2.8	0	0	0	0	161	92.5
12	9	5.1	3	1.7	4	2.2	0	0	16	9.1	142	81.6

The third, fourth and fifth research questions investigated whether there was a statistical difference between the levels of scientific knowledge of the participants according to gender, department and grade level. Prior to the analyses, it was examined whether the data met the assumption of normal distribution for all variables (see Table VI). It was found that the kurtosis and skewness values for all variables were not within the range of –1 and +1. Kurtosis and skewness values between –1 and +1 are considered indicators of normal distribution.[36] In addition, the results of the Kolmogorov-Smirnov test were examined and it was found that the *p*-values were less than 0.05. As the data were not normally distributed, differences between two groups were analysed using the Mann Whitney U test, and differences between more than two groups were analysed using the Kruskal-Wallis test.

TABLE VI. Normal distribution of data according to variables

Sample		*N*	Mean	Median	*SD*	Kurtosis	Skewness
Gender	Female	75	7.29	6.00	5.54	1.401	1.019
	Male	99	6.29	5.00	5.64	0.256	0.998
Grade level	Second	74	5.31	5.00	4.30	–0.093	0.715
	Third	65	7.61	5.00	6.38	–0.405	0.783
	Fourth	35	8.05	8.00	5.98	1.540	1.007
Department	Science teacher	56	8.28	8.00	4.92	2.739	1.204
	Mechanical engineering	41	6.58	5.00	4.75	–0.504	0.702
	Civil engineering	29	8.65	8.00	7.32	–0.944	0.507
	Electrical-electronics engineering	48	3.85	3.00	4.74	3.750	1.905

Findings for the third research question

The third research question was: Is there a difference between university students' level of scientific knowledge regarding chemical reaction arrows and electron arrows according to gender? The Mann Whitney *U* test was used to determine whether there was a statistically significant difference between the groups according to gender (see Table VII). According to the analysis results, it was found that there was no statistically significant difference between male and female participants' levels of scientific knowledge regarding chemical reaction arrows and electron arrows.

Table VII. Comparison of test scores by gender

Group	*N*	Mean ranks	Sum of ranks	*U*	*p*
Female	75	94.29	7072.00	3203.000	0.120
Male	99	82.35	8153.00		

Findings for the fourth research question

Another research question was: Is there a difference between university students' levels of scientific knowledge regarding chemical reaction arrows and electron arrows according to department? The data were analysed using the Kruskal Wallis test (see Table VIII) and according to the results of the analysis, there were significant differences between the groups according to departments. These differences were between science teachers and electrical and electronics engineering students ($U = 550.500$; $p < 0.05$). In addition, significant differences were found between mechanical engineering ($U = 602.500$; $p < 0.05$), civic engineering ($U =$

= 424.000 $p < 0.05$) and electrical and electronics engineering students. These differences were against electrical and electronics engineering students.

Table VIII. Comparison of test results by undergraduate program

Department	*N*	Mean ranks	*df*	x^2	*p*
Science teacher	56	106.88	3	26.996	0.000
Mechanical engineering	41	88.73			
Civil engineering	29	98.24			
Electrical-electronics engineering	48	57.35			

Findings for the fifth research question

Another question of the research was: Is there a difference between university students' level of scientific knowledge regarding chemical reaction arrows and electron arrows according to grade level? The data were analysed using the Kruskal-Wallis test (see Table IX) and according to the results of the analysis, there were significant differences between the groups according to grade levels. These differences were between the second and fourth grades ($U = 942.000$; $p < 0.05$) and in favour of the fourth grade.

Table IX. Comparison of test results by grade level

Grade level	N	Mean ranks	*df*	x^2	*p*
Second	74	77.04	2	6.000	0.050
Third	65	92.88			
Fourth	35	99.63			

DISCUSSION AND CONCLUSION

A four-tier diagnostic test was developed to determine the level of scientific knowledge of university students regarding chemical reaction arrows and electron arrows. Item analysis was used to calculate the difficulty and discrimination indices of the test items. The average difficulty index of the test was 0.28, and the average discrimination index was 0.52. In addition, the reliability coefficient of the test was found to be 0.76 using the KR-20 formula. Item difficulty scores must be between 0 and 1. If the score is below 0.30, it is a difficult item; if it is between 0.30 and 0.70, it is an item of medium difficulty; and if it is above 0.70, it is an item of easy difficulty.[37] The average difficulty of the test is expected to be 0.50. If the item discrimination value is 0.19 and below, the item should be removed from the test, items in the range 0.20–0.29 should be corrected, items in the range 0.30–0.39 are good items, and items 0.40 and above are very good items.[37] Based on these results, it can be said that the diagnostic test is difficult and distinctive for university students. In addition, if the reliability coefficient is greater than 0.70, the test is reliable.[38] When these results were evaluated together, a diagnostic test was developed that ensured reliability and validity. In addition, for most of the questions, the percentage of participants with positive and negative false was less than 10 %. Researchers recommend that the percentage of positive and negative false in a test should be less than 10 %.[39] The lower this percentage, the higher the validity of the test. The first task of the research was to develop a four-tier diagnostic test, tested for validity and reliability, for researchers wishing to determine the level of scientific knowledge of university students in relation to chemical reaction arrows and electron arrows. There have been studies in the literature to develop a four-tier diagnostic test.[40–42] Researchers developed a four-tier diagnostic test to assess upper secondary school students' understanding of isomers.[40] Researchers reported that the Cronbach alpha coefficient of the test was greater than 0.70 for each tier and dimension. In another study, researchers developed a four-tier diagnostic test to identify high school students' misconceptions about alcohols and carbonyl compounds.[41] The researcher calculated the McDonald's ω value of the test to be 0.85 for the response tier, 0.83 for the reason tier, and 0.86 for both tiers. In another study, a four-tier diagnostic test was developed to assess university students' understanding of transition metal chemistry, a topic in inorganic chemistry.[42] The researchers reported that the diagnostic test was difficult for students to complete and the Cronbach alpha reliability coefficient of the test was 0.60. Similar to the current research findings, the above studies also reported modest reliability values for their four-tier tests. Diagnostic tests can be used both to identify misconceptions and to determine students' levels of scientific knowledge. Studies on misconceptions have generally considered misconceptions detected at 10 % or more.[28,34] The percentage of students with misconceptions was below 10 % for all questions. For this reason, the test developed in this study was used to determine the level of students' scientific knowledge about chemical reaction arrows and electron arrows.

Another result of the research was that university students were deficient in recognizing chemical reaction arrows and electron arrows and in understanding their functions. The percentage of those who had scientific knowledge about chemical reaction arrows and electron arrows was between 0.5 and 17.2 %. In addition, more than half of the university students lacked knowledge on all questions. It was found that the participants' level of scientific knowledge about chemical reaction arrows was higher than their level of scientific knowledge about electron arrows. The percentage of those with a lack of knowledge in the questions about right arrows, left arrows, balance arrows and dynamic balance arrows was between 54.5 and 64.3 %. This rate was over 90 % for the questions on electron arrows. The researcher states that the use of curved arrows in organic chemistry is an excellent way of showing the flow of electrons as products are formed from reactants.[9] In his study, he noted that some students had difficulty using curved arrows correctly and attributed this to the fact that the basis of curved arrows was explained in few textbooks. A possible reason for the higher level of scientific knowledge about chemical reaction arrows than electron arrows among the participants in the current study may be that chemical reaction arrows are mentioned in more topics in chemistry courses. On the other hand, lack of confidence was greatest in the third (8.0 %) and fourth (8.6 %) questions. Although students answered the first and third tiers of these questions correctly, they were not confident of their answers. The third question was about the balance arrow and the fourth question was about the dynamic balance arrow. It was found that students were not confident in their answers to the arrows used to represent reversible reactions and chemical reactions at equilibrium. The reason why students are not confident in their answers may be that the balance arrows used to represent reversible reactions are now represented with half-hooked opposite double arrows to represent dynamic equilibrium.

In the research, it was found that university students' level of scientific knowledge about right arrow (it shows that the reactants are transformed into product), left arrow (it shows that products are transformed into reactants), balance arrow (it shows a reversible reaction) and dynamic balance arrow (it shows a chemical reaction in equilibrium) was higher than other chemical reaction arrows (balance arrows in favor of reactants/products, dashed arrow, broken arrow and crossed arrow) and electron arrows (resonance arrow, single-ended curved arrow, double-ended curved arrow). It was observed that the level of scientific knowledge of university students about resonance arrows (it shows the resonance relationship between two molecules) and balance arrows in favor of reactants/products (it shows the strong preference in the equilibrium reaction) was quite low (it was between 0.10 and 0.14 points out of 3 points). The percentage of those with no knowledge in the questions about resonance arrows and balance arrows in favor of reactants/products was over 90 %. The percentage of those with scientific knowledge was between 0.5 and 1.7 %. On the other hand, the level of scientific knowledge of the university students was below one out of three for the single-ended curved arrow (it shows the path of a single electron), the double-ended curved arrow (it shows the path of a pair of electrons), the dashed arrow (it shows that a chemical reaction is taking place but the conditions are unknown), the broken arrow (it shows reactions that have been tried but do not work) and the crossed arrow (it shows a reaction that cannot take place). The percentage of those with lack of knowledge on those questions was over 80 %. The percentage of those with scientific knowledge was between 2.8 and 5.1 %. Alchemists included arrows into their symbols hundreds of years before modern chemists included arrows in chemical equations.[8] Different types of arrows have different roles in chemistry. The complexity of the environment in which chemicals, glassware and other laboratory equipment are displayed in the virtual chemistry laboratory creates a cognitive load. For this reason, researchers conducted an experimental exercise in a virtual chemistry laboratory supported by arrow texts and found that the exercise improved students' performance in terms of time and errors.[43] Studies of the use of arrows in chemistry have tended to be in the area of organic chemistry. As students did not develop a conceptual understanding of organic chemistry, studies in the literature generally focused on the techniques of using, meaning and usefulness of the curved arrow in organic chemistry.[12] Researchers focused on how students made sense of the arrow and the common barriers to understanding.[14,44] The literature included module development studies that guided students to learn and apply the electron repulsion approach.[10] Another study found that using the arrow pushing approach in inorganic chemistry significantly increased the sense of participation in the lesson.[11] In another study, researchers described a new assessment technique that allows lecturers to ask open-ended questions about curved arrow representation in a multiple-choice format.[13] The above studies were generally conducted in the context of organic and inorganic chemistry courses and generally focused on curved arrows.

Finally, it was found that there was no statistically significant difference between participants' level of scientific knowledge about chemical reaction arrows and electron arrows according to gender. The effect of using labels and arrows in salt dissolution animation has been investigated in the literature.[15] The study reported that students with high spatial ability performed better than students with low spatial ability. It was also found that females outperformed males in the post-test. It was found that students in the animation group, where only arrows were used, scored lower than the other groups. The current study revealed differences in the scores of the chemical reaction arrows and the electron arrow diagnostic test between groups by department and grade level. These differences were in favor of fourth year students and against electrical and electronics engineering students. According to the researchers, advanced courses in chemistry education strengthened students' conceptual understanding. These courses introduced and used different arrow symbols to deepen understanding of chemical processes.[45] While students from the Faculty of Education (science teacher) took courses in analytical chemistry and organic chemistry in addition to general chemistry, students from the Faculty of Engineering only took courses in general chemistry. This situation showed that the educational process and advanced courses played an important role in increasing the scientific knowledge level of university students regarding chemical reaction arrows and electron arrows.

RECOMMENDATIONS AND LIMITATIONS

We developed a test to determine the scientific knowledge level of university students regarding chemical reaction arrows and electron arrows. This test was designed to determine whether there were differences in university students' scientific knowledge of chemical reaction arrows and electron arrows according to gender, department and grade level. Data were collected from students studying in four different undergraduate programs. It is recommended that future studies include students from other undergraduate programs taking chemistry courses. In addition, most of the research data was collected from students studying at two different universities. This situation is considered a limitation of the study. Students studying at different universities could be included in future studies.

Diagnostic tests can be used to reveal both misconceptions and students' level of scientific knowledge. The percentage of students with misconceptions was below 10 % for all questions in this study. Therefore, the test developed in this study was used to determine the level of students' scientific knowledge about chemical reaction arrows and electron arrows. Future studies could investigate students' misconceptions about chemical reaction arrows and electron arrows.

This study revealed university students' level of scientific knowledge about chemical reaction arrows and electron arrows. Future studies could investigate whether university students' use chemical reaction arrows and electron arrows correctly in concrete examples.

The study developed a four-tier diagnostic test. The second and fourth tier of this test were the confident tier. The confidence level had two options: confident and not confident. Future studies may prefer five-point Likert-type scales for confident tiers.

SUPPLEMENTARY MATERIAL

Additional data and information are available electronically at the pages of journal website: https://www.shd-pub.org.rs/index.php/JSCS/article/view/12942, or from the corresponding author on request.

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Ethics approval. Data was collected from human participants in the study. All ethical standards were taken into account and followed during the research. Ethical approval was obtained.

ИЗВОД

НИВОИ НАУЧНОГ ЗНАЊА УНИВЕРЗИТЕТСКИХ СТУДЕНАТА О СИМБОЛИЦИ СТРЕЛИЦА У ЈЕДНАЧИНАМА ХЕМИЈСКИХ РЕАКЦИЈА И О КРЕТАЊУ ЕЛЕКТРОНА

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Ово истраживање је имало за циљ да испита у којој мери студенти основних академских студија препознају и разумеју значење и функцију стрелица у једначинама хемијских реакција и о кретању електрона. Истраживање је спроведено применом компаративног истраживачког дизајна. Развијен је четвоpостепени дијагностички тест намењен процени знања о наведеним типовима стрелица. У фази развоја инструмента учествовао је 181 студент, а на основу добијених резултата израчунати су индекси тежине и дискриминативности

задатака. Коефицијент поузданости теста износио је 0,76. Након тога, тест је примењен на узорку од 174 студента с циљем утврђивања разлика у нивоу научног знања у зависности од пола, студијског програма и године студија. Резултати су указали на недовољан ниво научног знања студената о значењу и функцији стрелица у једначинама хемијских реакција и о кретању електрона. Више од половине испитаника показало је недовољно разумевање у свим питањима теста. Утврђено је да не постоје статистички значајне разлике у нивоу знања у односу на пол, док су уочене значајне разлике у односу на студијски програм и годину студија. Ове разлике су биле у корист студената четврте године, док су студенти електротехнике и рачунарства остварили слабије резултате.

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