Scientific paper

The Role of Heuristics in the Reasoning Process of Pre-Service Science Teachers on the "Chemical Structure – Acidity/Basicity Relationship" Topic

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Abstract

The purpose of this research is to examine the effects of 10 heuristics proposed by Talanquer on the reasoning processes of science teacher candidates on the "chemical structure – acidity-basicity relationship" topic. In this phenomenographic research, interviews were conducted with 30 prospective teachers enrolled in the Science Education Program, Education Faculty, Firat University in the spring semester of the 2018–2019 academic year. In the first stage of the two-stage interview, the participants were asked to rank some chemical compounds according to their increasing acidity strength, while in the second stage, they were asked to rank some chemical compounds according to their increasing basicity strength. In the interviews, participants were also asked to explain in detail the reasons for their ranking. From the answers given by the participants to the questions, six different answer patterns were obtained for acidity strength, while five different answer patterns were obtained for basicity strength. It was determined that all ten heuristics affect the reasoning of the participants, and because of the effects of heuristics, students generally use shortcut strategies instead of scientific reasoning. In addition, this study revealed that although it was not included in the model proposed by Talanquer, periodic trends heuristic also affected the reasoning of the participants on the "chemical structure – acidity/basicity relationship".

Keywords: Chemistry education, science education, heuristic, reasoning, acid-base

1. Introduction

Acid-base chemistry contains acid-base theories, auto-ionization of water, acid-base strengths, acid-base equilibriums, hydrolysis of salts, buffer solutions, acid-base reactions and acid-base titrations topics. Acid-base chemistry, which is highly related to daily life, occupy an important place in both science and chemistry curricula. Due to this importance, there are many studies in the literature on subjects such as the level of understanding of acid-base chemistry by students, the misconceptions regarding acid-base chemistry, and the effects of different teaching methods and activities on students' understanding of acid-base chemistry. In the literature these studies, it is reported that students' reasoning, judgment and decision-making processes about acid-base chemistry are generally imperfect.[1–3]

Negative situations such as imperfect reasoning, judgment and decision-making processes of the students has been encountered not only in the field of chemistry[4,5] but also in almost all disciplines.[6,7] Some scientists in different fields such as cognitive psychology, developmental psychology, and science/chemistry education, willing to investigate the reasons for individuals' imperfect reasoning, judgment and decision-making, have concentrated their research on cognitive constraints that guide individuals' reasoning. As a result of these studies, it was revealed that some mental structures that facilitate the decision making of individuals also contain various cognitive factors that restrict scientific reasoning.[8–12] Some of these cognitive elements include implicit assumptions,[13] core knowledge,[14] basic hypotheses and ontological beliefs,[15] intuitive rules,[16] primitive phenomenologies,[17] inductive constraints,[18] conceptual sources[19] and heuristics.[20]

The heuristics that restrict scientific reasoning are related to the Type 1 processes included in the "dual process" theory, which was developed to explain the individuals' judgment and decision-making processes.[21–23] According to this theory, two distinct processes called Type 1 and Type 2 are effective in the reasoning of individuals. Type 1 processes are automatic and very fast processes that do not care about the use of working memory.[21,24,25] No special effort is required to trigger Type 1 processes that progress independently of cognitive ability.[21,26] Type 1 processes are autonomous and are related to the intuitive reasoning of individuals.[26] Learned strategies and naturally occurring reasoning play an important role in type 1 processes.[11] Type 2 processes that require special cognitive effort and conscious intervention are slow processes that progress sequentially. Type 2 processes in which working memory is actively used are related to the effective, analytical and scientific thinking of individuals.[21,24,25,27] The Type 1 processes in the dual-process theory described in detail above, are short-path reasoning strategies and are called heuristics.[21,28,29] In conditions where knowledge or motivation is lacking or when time is limited, heuristics play an extremely active role.[21,30,31] As they evaluate fewer factors and use fewer cues in reasoning and judgment processes, heuristics enable decision-making in a short time without cognitive effort.[32] However, heuristics are also responsible for various cognitive biases observed in reasoning processes.[11,21]

Science/chemistry educators, who examine the judgment, reasoning and decision-making processes of students related to chemistry subjects, have started to benefit from the dual process theory and especially the heuristics, which is frequently mentioned in this theory, since the 2010s. There have been studies in the literature investigating students' intuitive reasoning and heuristic uses in chemistry subjects for a recent time. Chemistry topics in which students' intuitive reasoning and heuristic uses are examined in detail include "bond theories and molecular structures", "chemical problem solving", "addition reactions", "elimination reactions", "chemical reactivity", "acidity strength of molecules", "structure-property relationships of molecules", "classification of chemical substances" and "interpretation of IR and NMR spectra".[12,21,27,29,33–36] In addition to these important studies mentioned above, Talanquer explained the frequently used heuristics in the field of chemistry according to the cognitive processes they used, and collected these heuristics under 10 headings.[11] Since the model of Talanquer can be used as a standard or reference in studies to be carried out on heuristics in the field of chemistry, it has a great importance. Many confusions can be avoided, such as naming heuristics that work with the same mechanism with different names by using this model as a standard in chemistry issues. The model of ten heuristics has been met with great interest in the scientific world, and recently some scientists have started to use this model as a reference or standard. For example, two different research groups investigating the heuristics used by students on the hydrogen bonding topic used the ten heuristic models proposed by Talanquer in their studies.[7,37] Talanquer described and explained each of the ten heuristics that can be effective in the reasoning process of students in chemistry subjects, in his theoretical work, with examples specific to the field of chemistry. These ten heuristics are:[11]

- *Associative activation*: Using mental structures present in memory to fill in the blanks.
- *Fluency*: Using of easily accessible cues in the process of solving the problem.
- *Attribute substitution*: evaluation of other easily accessible attributes instead of the target attribute / Substitution the original question with a simpler question.
- *One reason decision making*: Simplifying reasoning by using a single clue or factor in the process of problem solving.
- *Surface similarity*: The assumption that chemical compounds that are similar to each other in structural representation have similar properties and behavior.
- *Recognition*: More value to recognized objects / less value to unrecognized.
- *Generalization*: Generalization of learned models or rules
- *Rigidity*: Reasoning in an inflexible or non-creative way.
- *Overconfidence*: Exceeding true accuracy due to self-confidence in decision-making processes.
- *Affect:* A positive or negative emotion towards an event, an object, or anything that affects learning.

The purpose of this research is to examine the effects of ten heuristics proposed by Talanquer on the reasoning processes of science teacher candidates on the "chemical structure – acidity/basicity relationship" topic. Therefore, the research problem of this study can be expressed as follows: What is the role of the ten heuristics proposed by Talanquer in the reasoning processes of the science teacher candidates about the "chemical structure – acidity/basicity relationship"? The research questions of this study are as follows:

- Which heuristics affect the reasoning of the students in the process of performing a task in which the compounds are ranked according to their acidity or basicity strengths?
- How to explain the working mechanisms of these heuristics that effected the reasoning of the students in a way specific to the field of chemistry?

2. Method

2. 1. Participants

This study was carried out at Firat University, a state university, during the spring semester in 2018–2019 academic year. Thirty pre-service science teachers at 2^{nd}, 3^{rd} and 4^{th} grades in Science Teaching Program of Education Faculty voluntarily participated in the research. Sixteen of the participants were male and fourteen of them were female. While determining the students to participate in the study, the achievements of the students in General Chemistry I and General Chemistry II were taken into consideration. Participants were composed of students, 1/3 of whom failed these courses, 1/3 of whom were moderately successful, and 1/3 of whom were highly successful. Instead of using the real name of participants, codes have been given such as S1, S2, S3, S4 and so on...

2. 2. Instruments and Design

In this study, the phenomenographic research method, one of the qualitative research methods, was used to investigate the roles of heuristics in the reasoning processes of the participants on the subject of "chemical structure-acidity/basicity relationship". Phenomenography is a method used in educational research to reveal what different individuals understand or perceive from the same concept.[38,39] The interviews are generally used in phenomenographic research to obtain detailed information on the subject. Therefore, in the present study, interviews were conducted with the participants to accurately determine the reasoning of the participants about "ranking chemical compounds according to their increasing acidity/basicity strength" and to determine the heuristics used by the participants in this process.

In the first stage of the interviews, which were completed in two stages, the participants were asked to rank HCl, H_2S and HI compounds according to their increasing acidity strength, while in the second stage they were asked to rank KOH, $Mg(OH)_2$ and $Ca(OH)_2$ compounds according to their increasing basicity strength. In the interviews, participants were also asked to explain in detail the reasons for their rankings. Maeyer and Talanquer previously used these questions in a different study.[40] After these questions were asked to the students during the interviews, the participants were given 2 minutes to answer each question. It has been stated in the literature that intuitive judgment and decision-making will have a greater effect in cases where the time is limited.[21,22,29] For this reason, the time was limited. Then, in each of the interviews, participants were asked to explain in detail the reasons for their answers. There was no time limit for the participants to explain in detail the reasons for their answers. To determine whether rigidity, overconfidence and affect heuristics took part in the students' answering questions, some additional questions were asked to the participants, both before the relevant chemistry questions were asked to the participants and after the participants answered the questions. The procedures detailed below were used to determine whether rigidity, overconfidence and affect heuristics were effective in the participants' reasoning processes.

Rigidity: In this study, a method was followed to investigate the effects of rigidity heuristics: before asking the relevant chemistry questions to the participants, the following question was asked: "Do you have a constant judgment/bias about the ranking of compounds according to their increasing acidity/basicity strength? For example, do you have any approaches such as "I have judgments/reasoning regarding the order of compounds according to their increasing acidity/basicity strength, which I will not change regardless of the question, I always solve problems regarding the order of compounds according to their increasing acidity/basicity strength using my current judgments/reasoning"? The answers given by the participants to this question were carefully examined. Besides, during the interviews, special attention was paid to whether the participants actually solved the questions using the strategies they were used to before, and whether they were flexible in solving the questions.

Overconfidence: Before asking/showing the relevant chemistry questions to the participants, the following question was asked: "If you are faced with a question about ranking compounds according to their increasing acidity/basicity strength, what level of confidence do you have that you can answer the question correctly. How would you score your confidence level between 1 and 10 points (1 is the lowest, 10 is the highest)"? Immediately after the relevant chemistry questions were asked/shown to the participants, the following question was asked to the participants before the students started solving the question; "What level of confidence do you have that you can answer this question correctly?" Finally, after solving the relevant chemistry question, the following question was asked to the participants: "What level of confidence do you have in yourself that you answered this question correctly? In cases where 8, 9 or 10 points were given as an answer to these three questions, it has been coded as overconfidence heuristic. Students who gave such answers generally made the following statements: "I am confident; I definitely solved / will solve the question correctly".

Affect: Before asking/showing the relevant chemistry questions to the participants, the following question was asked: "How do you feel when talking about the ranking of compounds according to their increasing acidity/basicity strength? Have you experienced any positive or negative effects on this chemistry topic during your education? If there is such an event, is it still effective"? "Besides, after the mentioned chemistry questions were asked/shown to the participants, the following question was asked: You saw the question, what do you feel?" Affect heuristic was coded in cases where it was determined that the participant had negative or positive emotions due to experiences.

2. 3. Data Analysis

The interviews that were recorded with audio and visuals later were transcribed into written documents.

Thus, interview transcripts were produced for each student. With the analysis of the data obtained from the interview transcripts, heuristic reasoning was detected and coded. While coding, other similar studies on students' heuristic reasoning in chemistry were also used.[7,21,22,40]

In order to ensure the inter-rater reliability, eight interview transcripts related to acidity strength and eight interview transcripts related to basicity strength (approximately 25% of total interview transcripts) were selected and the selected interviews were first evaluated and encoded separately by both the researcher and the consultant. The results of both evaluators were compared with each other. The encodings were revised so that there was over 90% agreement between the evaluators. After this compliance was achieved, all remaining interview transcripts were evaluated and coded by the researcher. Ten heuristics proposed by Talanquer were used to create a coding scheme for heuristics. Except for rigidity, overconfidence and affective heuristics, encodings for the other heuristics were made by associating the specific expressions found in the explanations made by students to solve the questions with the heuristics. Specific student expressions that form the basis of coding were presented in the results and discussion section.

3. Results and Discussion

From the answers given by the participants to the questions, six different answer patterns were obtained for acidity strength, while five different response patterns were obtained for basicity strength. These different answer patterns, the numbers and percentages of the students who gave these answers are presented in Table 1.

Table 1. Answer patterns

Answer patterns	n	%
(Acidity Strength, HCl, H2S and HI Compounds)		
$HCl < HI < H_2S$	2	6.66
$HI < HCl < H_2S$	3	10.00
$HI < H_2S < HCl$	6	20.00
$H_2S < HI < HCl$	12	40.00
$HCl < H_2S < HI$	1	3.33
$H_2S < HCl < HI$ (Correct Answer)	6	20.00
(Basicity Strength, KOH, $Mg(OH)_2$ and $Ca(OH)_2$ Compounds)		
$KOH < Mg(OH)_2 < Ca(OH)_2$	8	26.26
$Mg(OH)_2 < Ca(OH)_2 < KOH$ (Correct Answer)	9	30.00
$KOH < Mg(OH)_2 = Ca(OH)_2$	3	10.00
$KOH < Ca(OH)_2 < Mg(OH)_2$	6	20.00
$Ca(OH)_2 < Mg(OH)_2 < KOH$	4	13.33

Two important factors affect the acidity strength of an acid that can be represented as E-H. These factors are the electronegativity and radius of the E atom. As the electronegativity of the E atom increases, it will be easier to separate the hydrogen as a proton (H^+). Therefore, acidity strength will increase. As the radius of the E atom increases, the E–H bond will become weaker. Therefore, hydrogen will be easily released in the form of proton (H^+), that is, the acidity strength will increase. In the periodic table, the radius decreases from left to right, while electronegativity increases. In the periodic table from left to right, the effect of electronegativity is more dominant than the effect of the radius in terms of the effect on the acidity strength. As a result, the acidity strength of the acids shown in the form of E–H increases from left to right in the periodic table. In the periodic table, the radius increases from top to bottom in a group, while electronegativity decreases. In the periodic table, from top to bottom, the effect of the radius is dominant over the effect of electronegativity in terms of the effect on the acidity strength. As a result, from top to bottom in the periodic table, the acidity strength of the acids shown in the form of E–H increases. Due to all these explanations mentioned, the correct answer to the question about acidity strength is $H_2S < HCl < HI$. Two important factors affecting the basicity of a base (where B stands for metal atom) that can be represented as a B–OH. These factors are the charge and radius of the metal atom (B). As the charge of the metal atom shown as B increases, the Coulomb attraction force between the metal atom and the OH group will increase and the separation of the hydroxyl ion will be difficult. Therefore, the basicity strength will decrease. As the radius of the B atom increases, the B–OH bond will become weaker. Therefore, hydroxyl (OH^-) will be easily released, that is, the strength of basicity will increase. The charge of B atom increases from left to right in the periodic table, however, the radius decreases. In the periodic table from left to right, the effect of the charge is more dominant than the effect of the radius in terms of the effect on the basicity strength. As a result, due to the reasons mentioned above, the basicity strength decreases from left to right in the periodic table for bases that can be represented as B–OH. In the periodic table, the charges of metals do not change from top to bottom in a group, and their atomic radii increase. As the radius of the B atom increases, the B–OH bond will become weaker and thus the OH group will be separated more easily. In other words, the basicity of metal hydroxides will increase from top to bottom in the same group in the periodic table. Because of all the explanations mentioned, the correct answer to the question about acidity strength is $Mg(OH)_2 < Ca(OH)_2 < KOH$.

Participants are expected to solve questions with the reasoning explained in detail above. However, in this study, it was determined that the rates of students who gave correct answers to the questions about acidity and basicity strengths were 20.00% and 30.00% respectively. Because scientific reasoning requires a great deal of cognitive effort, the majority of students may have answered the questions by relying on heuristic strategies that require less cognitive effort. Since the aim of this study was to examine the heuristic use of the students, the answers given by the students to the questions asked were examined in terms of heuristic use. For this purpose, specific expressions in each student's interview transcript were associated with 10 heuristics and encoded. Specific student expressions related to the solution of the problem related to acidity strength are given in Table 2. The periodic trends heuristic in Table 2 is

Table 2. Student Expressions Related to Heuristics (Acidity strength, HCl, H_2S and HI)

Heuristic Code	Summary of student statements
Associative activation	As the hydrogen number increases, acidity increases. Elements that are close to each other in the periodic table show similar chemical properties. Statements in which the "more electronegative, the stronger acid " approach is adopted. As the hydrogen number increases, acidity decreases. Acidity changes from left to right and from top to bottom in the periodic table. Statements in which "the larger the radius, the stronger acid" approach is adopted. The higher the molecular weight, the more acid.
Fluency	Using the hydrogen number in the molecule as an easily accessible clue/Using the number 2 in the H_2S compound as an easily obtainable clue.
Attribute Substitution	Replacing the original question with questions: Which compound has more hydrogen? What is the order of compounds regarding their molecular weight? What are the positions of the S, Cl and I atoms relative to each other in the periodic table? Which of the S and I atoms is closer to the Cl atom in the periodic table? What is the order of S, Cl and I atoms regarding their electronegativities? How are the S, Cl and I atoms ordered regarding their radii?
One-Reason Decision Making	Decision-making by evaluating only electronegativity. Decision-making by evaluating only radii. Decision-making based on whether to recognize one compound only. Decision-making by evaluating only the places of the atoms in the periodic table. Decision-making by evaluating only the weights of compounds.
Surface similarity	HI looks like HCl. HCl looks like HI. H_2S looks like H_2O.
Recognition	I know/recognize HCl (from the lab or from the class). I know/recognize HI (from lab or class). I do not know / have never heard of H_2S before.
Generalization	Generally, all properties increase / decrease in the periodic table from top to bottom, so acidity also increases / decreases from top to bottom. Generally, all properties increase / decrease in the periodic table from left to right, so the acidity also increases / decreases from left to right. Elements that are close to each other in the periodic table generally show similar chemical properties. Atoms with high electronegativity generally have high all other properties. Atoms with large radii generally have high all other properties.
Rigidity	I will decide the acidity strength based on the number of hydrogen in the compounds. I will decide according to the place of the atoms in compounds in the periodic table. I will decide based on the electronegativity of the atoms in compounds. I will decide according to the radii of the atoms in compounds.
Overconfidence	I definitely solved / will solve the problem correctly. My confidence level is 8-10.
Affect	I like / dislike the subject of relative acidity strength of compounds, positive / negative emotion.
Periodic Trends	Acidity increases / decreases from left to right in the periodic table. Acidity increases / decreases from top to bottom in the periodic table.

Periodic Trends: Periodic Trends heuristic is not included in the ten heuristics proposed by Talanquer. However, this heuristic was added to the list since it was determined that the participants in this study also used this heuristic.

not included in the ten heuristics proposed by Talanquer. However, since it was found in this study that the participants also used this heuristic, this heuristic was also taken into consideration and added to the table.

To facilitate comparisons and interpretations, the number and percentages of the participants who used the related heuristics at least once in the process of solving the question about acidity strength are given in Table 3. The percentages given in Table 3 express the ratio of the number of participants who used the relevant heuristics at least once to the total number of participants (N = 30, total number of participants).

Table 3. Number and percentages of participants using relevant heuristic at least once (acidity strengths, HCl, H_2S and HI)

Heuristics	n	% (N = 30)
Associative activation	20	66.66
Fluency	8	26.66
Attribute substitution	20	66.66
One reason decision making	9	30.00
Surface similarity	9	30.00
Recognition	20	66.66
Generalization	10	33.33
Rigidity	5	16.66
Overconfidence	4	13.33
Affect	5	16.66
Periodic trends	8	26.66

Specific student expressions related to the solution of the problem related to basicity strength are given in Table 4.

The number and percentages of the participants who used the related heuristics at least once in the process of solving the question about the basicity strength are given in Table 5. The percentages given in Table 5 express the ratio of the number of participants who have used the relevant heuristics at least once to the total number of participants (N = 30, total number of participants).

Table 5. Number and percentages of participants using relevant heuristic at least once (relative basicity strengths of compounds KOH, $Mg(OH)_2$ and $Ca(OH)_2$)

Heuristics	n	% (N = 30)
Associative activation	25	83.33
Fluency	11	36.66
Attribute substitution	25	83.33
One reason decision making	15	50.00
Surface similarity	3	10.00
Recognition	11	36.66
Generalization	14	46.66
Rigidity	5	16.66
Overconfidence	6	20.00
Affect	5	16.66
Periodic trends	12	40.00

In the process of solving a problem, individuals' evaluation of other and easily accessible attributes instead of the target attribute is a result of the effect of the attribute substitution heuristic.[11] Similarly, individual's unconscious replacement of the question asked to himself/herself by another simple question and focusing on the solution of this simple problem is a result of the attribute substitution heuristic. The electronegativities and radii of Cl, S and I atoms must be consciously evaluated in order to solve the problem related to the acidity strength by using scientific reasoning. Evaluating the electronegativities and radii of the Cl, S and I atoms is the implied target attribute of the question mentioned. However, in this study, when the reasoning of the participants about the solution of the problem related to acidity strength was examined, it was revealed that heuristics affected the participants' interpretation of the question, and thus, there were differences between the target attribute and the comments expressed by the students. In the process of solving the problem related to acidity strength, it was found that, due to the effect of attribute substitution heuristic, twenty of the participants evaluated other attributes instead of the intended target attribute or unconsciously evaluated the intended target attribute. Thus, after reading the question, they replaced the original question with another simple question. The mentioned students focused on the answer to another simple question. Instead of the original question, the different questions that mentioned students focused on in the process of solving the problem related to acidity strength are collectively given in Table 2. Due to the effect of attribute substitution heuristic in the process of solving the problem related the basicity strength, it was determined that twenty-five of the participants evaluated other attributes instead of the intended target attribute or unconsciously evaluated the intended target attribute. Thus, they replaced the original question with another simple question after reading the question. Instead of the charge and radius of the metal atom, these participants evaluated other attributes or unconsciously evaluated the radius, and focused on the answer to another simple question. The questions students focused on in the process of solving the problem related to basicity strength instead of the original question are collectively given in Table 4.

It is reported in the literature that more than one heuristics are effective in the decision-making processes of individuals and that these effective heuristics promote and trigger each other.[11,22] Similar to this situation stated in the literature, in this study, it was concluded that more than one heuristics were effective at the same time. The reasoning of the S14 coded student during the process of solving the question about acidity strength can be given as an example in which more than one heuristics are effective at the same time. From the statements of the S14 coded student, it is understood that fluency, associative activation, attribute substitution and recognition heuristics are effective in the student's problem-solving process. For a person

Table 4. Student Expressions Related to Heuristics (Basicity strength, KOH, $Mg(OH)_2$ and $Ca(OH)_2$)

Heuristic Code	Summary of student statements
Associative activation	The more the number of hydroxyl groups, the higher basicity. Statements in which "the more electronegative, the stronger base" approach is adopted. Basicity changes from left to right and from top to bottom in the periodic table. Statements in which the "larger radius, the stronger base" approach is adopted. A compound with a large molecular weight is more basic.
Fluency	Using the number of hydroxyl groups in the compound as an easily accessible clue / using the number 2 in the compounds $MgOH)_2$ and $Ca(OH)_2$ as an easily accessible clue.
Attribute substitution	Replacing the original question with questions: Which compound has more hydroxyl groups? What is the order of compounds regarding their molecular weight? How are the positions of K, Mg and Ca atoms relative to each other in the periodic table? What is the order of K, Mg and Ca atoms regarding their electronegativities? What is the order of the K, Mg and Ca atoms regarding their radii?
One reason decision making	Decision-making by evaluating only electronegativity. Decision-making by evaluating only radii. Decision-making based on whether to recognize one compound only. Decision-making by evaluating only the places of the atoms in the periodic table. Decision-making by evaluating only the weights of compounds.
Surface similarity	$Mg(OH)_2$ looks like $Ca(OH)_2$.
Recognition	I know/recognize KOH I know/recognize $Ca(OH)_2$ I do not know/recognize $Mg(OH)_2$. I have never heard it before.
Generalization	Generally, all properties increase/decrease in the periodic table from top to bottom, so basicity also increases/decreases from top to bottom. Generally, all properties increase/decrease in the periodic table from left to right, so the basicity also increases/decreases from left to right. Elements that are close to each other in the periodic table generally show similar chemical properties. Atoms with high electronegativity generally have high all other properties. Atoms with large radii generally have high all other properties.
Rigidity	I will decide the basicity strength based on the number of hydroxyl in the compounds. I will decide according to the place of the atoms in compounds in the periodic table. I will decide based on the electronegativity of the atoms in compounds. I will decide according to the radii of the atoms in compounds.
Overconfidence	I definitely solved/will solve the problem correctly My confidence level is 8–10.
Affect	I like/dislike the subject of relative basicity strength of compounds, positive/negative emotion.
Periodic trends	Basicity increases / decreases from left to right in the periodic table. Basicity increases / decreases from top to bottom in the periodic table.

Periodic Trends: Periodic Trends heuristics is not included in the ten heuristics proposed by Talanquer. However, this heuristic was added to the list since it was determined that the participants in this study also used this heuristic.

who is new to any field, it is easier to examine explicitly given properties than implicitly given properties. People tend to use easily accessible information when making judgments and decisions. Individuals' use of easily accessible cues to solve the problem is associated with the fluency heuristic.[11] Therefore, the S14 coded student's use of the number 2 in H_2S (the number of hydrogen atoms in the compound) as an easily accessible clue is associated with the fluency heuristic. Associative activation heuristic shows its effect by unconsciously using the existent mental constructions in that person's memory when faced with a new problem. With the effect of associative activation heuristic, individuals generally use straight or inverse proportion approaches, which can be expressed as "More A-More B" or "More A-Less B".[11] S14 coded student's relationship between acidity and hydrogen and adopting an approach such as "more hydrogen – more acid" is related to associative activation heuristic. In this process, the student focused on a simpler question such as "Which compound has more hydrogen" instead of the original question. This situation is associated with attribute substitution heuristic. Recognized objects or events have a strong influence on the decisions people make. In cases where individuals recognize one of more than one object and do not recognize the others, they give higher value to the object they recognize. HCl is a chemical compound that students often hear its name. The name of the compound HCl is frequently mentioned in lectures. In addition, this compound is frequently used in many experiments in laboratories. The fact that the S14 coded student gave more value to HCl, which he knew before, and therefore said that HCl is a stronger acid than HI, shows that the recognition heuristic is effective in the reasoning process of this participant.

The fact that some of the participants used the number 2 (the number of hydroxyl groups in the compounds) as an easily accessible clue in $Mg(OH)_2$ and $Ca(OH)_2$ compounds in the process of solving the problem related to the basicity strength is also related to the fluency heuristic. In the process of solving the problem related to the basicity strength, the fact that some of the participants adopt the flat proportion approach expressed as "more hydroxyl – more basic" is related to the associative activation heuristic. In the question about basicity strength, KOH is a chemical compound that students often hear its name. With the effect of recognition heuristic, some of the students evaluated KOH as the compound with the highest basic strength. Some of the students stated that the $Ca(OH)_2$ compound is named as slaked lime in daily life and they have heard its name many times before and therefore they know this compound. With the effect of recognition heuristics, some of the students evaluated $Ca(OH)_2$ as the compound with the highest basic strength. The students' thinking of KOH or $Ca(OH)_2$ as the compound with the highest basicity strength among the compounds in the question with such approaches shows that the recognition heuristic is effective.

The assumption that chemical compounds resembling each other in structural representation are members of the same category and that such compounds have similar properties and behavior is a result of the effect of the surface similarity heuristic. The reasoning of the S3 coded student during the process of solving the question about the basicity strength can be given as an example reasoning process in which the surface similarity heuristic is effective. The S3 coded student's evaluation of $Mg(OH)_2$ and Ca $(OH)_2$ compounds as having the same basicity strength because they are very similar to each other shows that the surface similarity heuristic is effective in this process. In the process of solving the problem related to the acidity strength, some of the participants used one of the approaches such as "HI looks like HCl", "HCl looks like HI" or "H_2S looks like H_2O". These students think that similar compounds will have the same properties. For example, the S9 coded student's "H_2S looks like H_2O. H_2O is neutral. Since it is similar to H_2O, it is likely that H_2S is also neutral or very weak acid" shows that the surface similarity heuristic is effective in this process.

Individuals' extra generalization of previously learned patterns or rules, using the knowledge they have gained from a few previous experiences, without considering all variables, is considered an effect of the generalization heuristic. In this study, it was determined that the generalization heuristic was effective in the decision-making processes of some of the participants in the process of solving the problem related to both acidity and basicity strength. Regarding the acidity and basicity strengths, the participants' expressions determined by this study and revealing that the generalization heuristic is effective were given in Table 2 and Table 4, respectively. In all processes in which generalization heuristic was effective, associative activation heuristic was also effective. These two heuristics triggered and supported each other. The reasoning of the S4 coded student in the process of solving the first question can be given as an exemplary reasoning process in which generalization and associative activation heuristics are effective at the same time. The approach of the student coded S4 that "all other properties of atoms with high electronegativity are generally also high" shows that the generalization heuristic is effective in this process. In this process, the student decided by using the approach that "Probably, the acidity of the compounds formed by the bonding of high electronegativity atoms to hydrogen will also be high". Such an approach shows that the student is relying on a straight-proportion logic expressed as "the more A – the more B". The student's decision with such an approach shows that the associative activation heuristic is also effective in this process.

Individuals generally facilitate reasoning by using a single clue or factor to give a logical answer. In doing so, they use the first feature that comes to mind. S4 coded student made a decision based on only one reason. The S4 coded student only evaluated electronegativity during the decision-making process regarding the question. For this reason, the one-reason decision-making heuristic was also effective in the decision-making process of the S4 coded student. The attributes evaluated by the participants who made a decision based on only one reason in the process of solving the problems regarding acidity and basicity strength were given in Table 2 and Table 4, respectively.

Three of the students stated that they generally hate verbal chemistry subjects, they mainly consider themselves closer to numerical logic, that there are more subjects that require chemical and mathematical processing in chemistry lessons, they do not like to deal with abstract concepts and the relationships between these concepts. As a result, they stated that they did not like and were not interested in the ranking of compounds according to their acidity/basicity strength, as it was the subject of verbal chemistry. Affective heuristic was coded based on these expressions of the mentioned students. Two of the participants stated that they had a special interest in the periodic table and that they liked topics of the periodic table and the changing properties throughout the periodic table. These students also stated that they knew whether all properties such as atomic radius, ionization energy, electron affinity, acidity and basicity increased or decreased from left to right or from top to bottom in the periodic table. These students also stated that even if they do not know exactly the factors that affect the change of these characteristics, it is sufficient for them to know whether they increase or decrease in the periodic table from top to bottom or from left to right. Based on these expressions of mentioned students, affective heuristics were also coded for these students.

In this study, the procedure described in detail under the title of method was followed to investigate the effects of rigidity heuristics. In order to investigate the effects of rigidity heuristics, the answers given to the questions by the participants were carefully examined. In addition, during the interviews, special attention was paid to whether the participants actually solved the question using the strategies they were used to before, and whether they were flexible in solving the question. As a result of these operations, it was concluded that the rigidity heuristic had an effect on the problem-solving process of five students. The mentioned students stated that regardless of the question/s about the relative acidity/basicity strength of the compounds, they have the approach they believe and rely on to solve the question/s and that they will solve the question/s according to these approaches. The reasoning of the students in the process of solving the questions was examined carefully and it was determined whether these students were flexible in the process of solving the questions. The strategies that the participants declared that they would use in the process of solving the questions about acidity and basicity strengths are presented in Table 2 and Table 4, respectively.

In this study, the procedure described in detail in the method section was followed to investigate the effects of overconfidence heuristic. In order to investigate the effects of overconfidence heuristic, the answers given by the participants to the questions (three questions) were carefully examined. The overconfidence heuristic was coded when 8, 9 or 10 was given as an answer to these three questions. Students who gave this kind of answer usually made the following kinds of statements: "I am confident in myself; I have definitely solved the question correctly". As a result of the procedures performed by following the procedure described in detail above, it was determined that overconfidence heuristic was effective in reasoning about the acidity strength of the four participants and also in reasoning about basicity of the six participants.

Periodic trends heuristic is not included in the ten heuristics proposed by Talanquer. However, since it was determined in this study that the participants also used this heuristic, this heuristic was also taken into consideration. The periodic trends heuristic is also called arbitrary heuristic by some researchers. It is a result of the effect of periodic trends heuristics to make the evaluations such as only the feature increases or the feature decreases without knowing why the features changing from left to right and from top to bottom in the periodic table. It was determined that the periodic trends heuristic was effective in the reasoning processes related to the acidity strength of the eight students. In addition, it was determined that the periodic trends heuristic was effective in the reasoning processes related to the basicity strength of the twelve students. Associative activation, attribute substitution, and generalization heuristics also played an active role in many of the reasoning in which periodic trends heuristic exhibited. These four heuristics triggered and supported each other.

The misconceptions about acid-base strength, which are widely stated in the literature, are: The acidity of a compound increases with the increase in the number of hydrogen in the compound.[2,41] The basicity of a compound increases with the increase in the number of hydroxyls in the compound.[42,43] pH is a measure of acid strength.[2] The pH value of the solution is inversely proportional to the strength of the acid; the lower the pH value of the solution, the higher the acidic power of the solution.[3] For compounds shown as HX, the more electronegativity of the halogen atom (X), the higher the acidity.[3] Concentration indicates the acid-base strength.[44,45] The Kb value reflects the concentration of the basic solution.[1] Diprotic acid is stronger than monoprotic acid.[46] All acids are strong acids.[44,45] In this study, the main purpose of which was to examine the heuristic uses of the students, in-depth interviews with the participants regarding the acidity and the basicity strength of the compounds allowed to observe some misconceptions held by the students. The misconceptions determined in this study are as follows: "As the number of hydrogen in compounds increases, the acidity strength of the compounds increases". "As the number of hydrogen in the compounds increases, the acidity strength of the compounds decreases". " As the number of hydroxyls in the compounds increases, the basic strength of the compounds increases". "For hydrogen halides shown as HX, the acidity strength decreases from top to bottom in the periodic table". "For hydrogen halides shown in the form of HX, as the electronegativity of the halogen atom (X) increases, the acidity strength increases". "As the molecular weights of the compounds increase, the acidity strength increases". "As the molecular weights of the compounds increase, the basicity strength increases". "As the electronegativity of the atom to which the hydroxyl group is attached increases, the basicity strength increases". The misconceptions determined in the present study and the misconceptions determined in the different studies in the literature are generally similar. However, different from the misconceptions found in the literature, in this study, it was determined that the students correlated the acidity or basicity strengths with the molecular weights of the compounds.

The fact that the participants used heuristics frequently caused the rate of students who gave correct answers to the questions to be low. In many studies in the literature on students' reasoning in chemistry subjects, similar to the results of the present study, the accuracy rates of participant answers were generally low. For example, in two different studies on students 'understanding of hydrogen bonding, the accuracy rate of participants' answers was found to be 27.00% and 16.66%.[7,37] The accuracy rate of the participants' answers was found to be 36.00% in a study on "chemical bond theories and molecular structures", and 31.00% in a study on addition reactions.[33,21]

There is only one study in the literature that examines the heuristic reasoning of the students in the process of performing a task where it is desired to rank HCl, H_2S and HI compounds according to their increasing acidity strength and KOH, $Mg(OH)_2$ and $Ca(OH)_2$ compounds according to their increasing basicity strength.[40] In the mentioned study, it was determined that the heuristics of "recognition", "one reason decision making", "arbitrary/periodic trends" and "representativeness" were effective in the reasoning processes of the participants, and explanations and comments were made based on these four heuristics. In the present study, the reasoning of the participants was examined based on 10 heuristics. In order to present the results of the current research visually, the frequencies of the participants' use of the heuristics are given as a graphical representation in Figure 1.

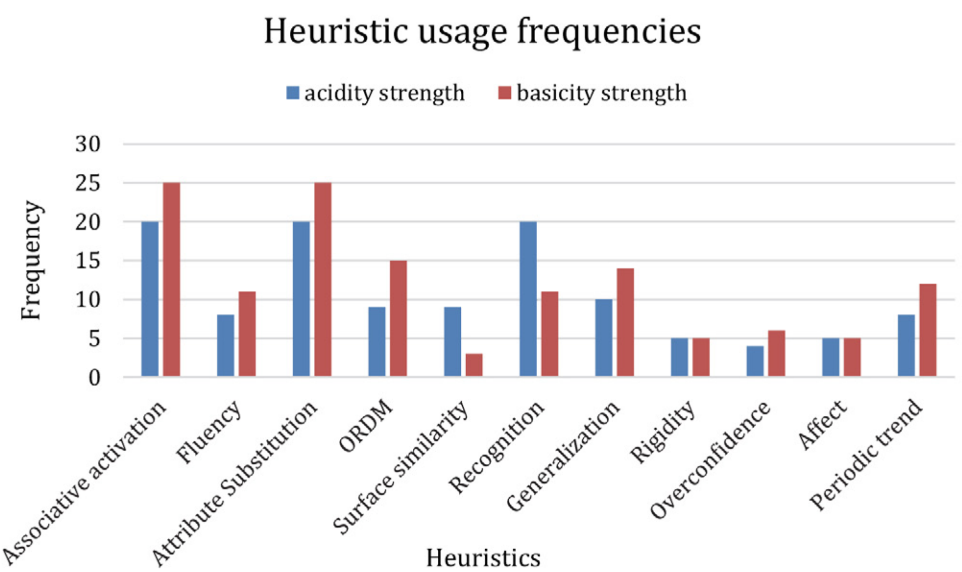

Figure 1. Graphical presentation of heuristic usage frequencies

In the study conducted by Maeyer and Talanquer[40] on the ranking of HCl, H_2S and HI compounds according to their increasing acidity strength and KOH, $Mg(OH)_2$ and $Ca(OH)_2$ compounds according to their increasing basicity strength, the accuracy rate of student answers to both questions was determined as 20.60%. In the mentioned study, it was also stated that the percentage of participants using one-reason decision-making, recognition and periodic trends heuristics were 50.00%, 79.40% and 11.80% respectively for the question related to acidity strength and 67.60%, 35.30% and 41.20% respectively for the question related to basicity strength. In the current study, in which the students were asked to solve the same questions, the accuracy rate of the student answers for the question about acidity strength was found to be 20.00%, and 30.00% for the question about the basicity strength. In the current study, it was also determined that the percentage of participants using one-reason decision-making, recognition and periodic trends heuristics were 30.0%, 66.66% and 26.66% respectively for the question related to acidity strength and 50.00%, 36.66% and 40.00% respectively for the question related to basicity strength. The accuracy rates of student answers determined by the present study are similar to the rates determined in the study conducted by Maeyer and Talanquer.[40] The usage percentages of one-reason decision making, recognition and periodic tendency heuristics determined in the study conducted by Maeyer and Talanquer[40] and the usage percentages determined by this study are generally different. On the other hand, in the solution processes of the questions about the acidity/ basicity strength, the explanations and determinations made in the present study about the action mechanisms of these three heuristics and the explanations and determinations made by Maeyer and Talanquer[40] are similar.

This study revealed that when faced with questions about "chemical structure – acidity/basicity relationship", pre-service science teachers rely heavily on intuitive reasoning rather than analytical thinking in decision-making processes, and students frequently use heuristics. These heuristics reduced the cognitive effort in students and caused students to produce incorrect answers. Except for two studies on students' understanding of hydrogen bonding, the ten heuristic models proposed by Talanquer were not used in all other studies examining the effects of heuristics on chemistry subjects. With the current research carried out to fill this gap in the literature, the effects of all 10 heuristics proposed and defined by Talanquer on students' reasoning processes on the "chemical structure – acidity/basicity relationship" were examined in detail.

4. Conclusions

In the process of ranking compounds according to their increasing acidity/basicity strength, the roles of all ten heuristics proposed by Talanquer were examined for the first time in this study. This study, in which the subject of "chemical structure – acidity/basicity relationship" was evaluated and examined in the context of a cognitive psychology theory, will make an important contribution to the literature in this sense. The fact that the students used heuristics frequently in the process of answering the questions shows that most of the students preferred shortcut strategies instead of scientific/chemical reasoning. The heuristics identified in this study are typical examples of cognitive constraints that restrict students' scientific reasoning under conditions where time and knowledge are limited. These heuristic strategies have allowed students to reduce cognitive effort and produce answers in the absence of necessary information, but these cognitive constraints often misled students and caused them to give incorrect answers. Knowing how students think about the "chemical structure – acidity/basicity relationship" and the role of heuristics in this topic can help chemistry educators to develop strategies that encourage meaningful learning about the "chemical structure – acidity/basicity relationship". In order to develop measurement tools that will evaluate student learning validly and reliably, it is useful to examine students' general and field-specific reasoning strategies in detail. Therefore, this study may contribute to the development of measurement tools in the field of chemistry. For example, this study revealed that particular attention should be paid to chemical molecules or compounds involved in chemistry questions to be asked. In the chemistry-related questions in this study, an important effect of fluency heuristics was found, as there are clues that participants can easily obtain in the structural representation of the compounds. In addition, the fact that the compounds that the students knew before, such as HCl or KOH, were also included in the questions caused the recognition heuristic to be used by most of the participants. Knowing these and similar situations and results will be useful for instructors who will prepare questions to evaluate students.

As heuristic reasoning is unconscious, automatic, fast, and cognitively economic, students frequently use it. Developing analytical reasoning skills instead of heuristic reasoning are a very time-consuming and difficult process, as students often have the habit of using heuristics for the reasons mentioned above. We believe that it would be beneficial to give more importance to the education of students in judgment and decision-making strategies in order to contribute to students' decision making with scientific reasoning instead of heuristic reasoning.

The reason why heuristic strategies are frequently used may be that the shortcut problem solving strategies taught to students throughout their education have reduced students' tendency to use scientific reasoning skills. Thus, students may have acquired the habit of solving problems using shortcut strategies. One of the most common types of reasoning is intuitive reasoning. Therefore, the task of educators is not to prevent an intuitive judgment, but to investigate how intuitive judgment affects students' understanding and interpretation, and to create successful reasoning and thinking methods specific to the field after carefully analyzing the data obtained from these studies. While a subject is being taught to students in chemistry lessons, it can be very useful to explain the wrong reasoning ways that can be encountered due to frequently used shortcut strategies about that topic. It is often recommended that students be asked to solve different and new types of chemistry questions in order to gain the habit of solving questions using chemical processes instead of shortcut reasoning strategies that are unrelated to scientific reasoning.

In this study, data were collected from a limited number of student enrolled in the Science Teaching Program of Firat University. As a necessity of the interview method, the fact that a small number of participants were interviewed is a limitation of this study. For this reason, we recommend that similar studies be carried out in different institutions. The participants who were interviewed within the scope of this study were determined on a voluntary basis and no reward was given to these participants for their time and effort. Another limitation of this study is the possibility that this situation negatively affects the students' motivation to spend time and their cognitive efforts to answer the questions. More studies are also needed on how Type 2 processes can be activated more to correct biases caused by Type 1 processes in different chemistry issues. In addition, it is beneficial to investigate the effects of various teaching strategies that will be planned to eliminate the negative effects of heuristics that affect chemistry subjects.

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Conflicts of Interest

The authors declare no conflict of interest.

5. References

1. R. Artdej, T. Ratanaroutaia, R. K. Collb, T.Thongpanchange, *Res. Sci. Technol. Educ.* **2010**, *28*, 167–183. **DOI:**10.1080/02635141003748382
2. G. Demircioğlu, A. Ayas, H. Demircioğlu, *Chem. Educ. Res. Pract.* **2005,** *6,* 36–51. **DOI:**10.1039/B4RP90003K
3. A. Mutlu, B. C. Sesen, J. *Balt. Sci. Educ*. **2016**, *15*, 79–96.
4. M. Slapničar, V. Tompa, S. A. Glažar, I. Devetak, J. Pavlin, *Acta Chim. Slov.* **2020**, *67*, 904–915. **DOI:**10.17344/acsi.2020.5908
5. R. Kozma, E. Chin, J. Russell, N. Marx, J. Learn. Sci. **2000**, 9,105–143. **DOI:**10.1207/s15327809jls0902_1
6. K. S. Taber, *Chem. Educ. Res. Pract.* **2001,** *2,* 123–158. **DOI:**10.1039/B1RP90014E
7. K. Miller, T. Kim, *Biochem. Mol. Biol. Educ.* **2017***, 45*, 411–416. **DOI:**10.1002/bmb.21061
8. G. Hatano, K. Inagaki, *Int. J. Behav. Dev.* **2000**, 24, 267 – 275. **DOI:**10.1080/01650250050118240
9. F. C. Keil, *Cogn. Sci.* **1990**, *14*, 135–168. **DOI:**10.1207/s15516709cog1401_7
10. H. M. Wellman, S. Gelman, In: D. Kuhn, R. Siegler (Eds.): Cognition, perception and language. Handbook of child psychology, Wiley, New York, **1998**, pp. 523–573.
11. V. Talanquer, *J. Chem. Educ.* **2014***, 91,* 1091–1097. **DOI:**10.1021/ed4008765
12. J. Maeyer, V. Talanquer, *J. Res. Sci. Teach.* **2013***, 50,* 748–767. **DOI:**10.1002/tea.21092
13. S. Vosniadou, *Learning and Instruction*, **1994**, *4*, 45–69. **DOI:**10.1016/0959-4752(94)90018-3
14. E. S. Spelke, K. D. Kinzler, *Dev. Sci.* **2007**, *10*, 89–96. **DOI:**10.1111/j.1467-7687.2007.00569.x
15. M. T. H. Chi, In S. Vosniadou (Ed.), International Handbook of Research on Conceptual Change, Routledge, New York, **2008**, pp. 61–82.
16. R. Stavy, D. Tirosh, How students (mis-)understand science and mathematics: Intuitive rules. Columbia University, Teachers College Press, New York, **2000.**
17. A. A. diSessa, *Cognition and Instruction*, **1993**, *10*, 165–255. **DOI:**10.1080/07370008.1985.9649012
18. A. Perfors, J. B. Tenenbaum, T.L. Griffiths, F. Xu, *Cognition*, **2011**, *120*, 302–321. **DOI:**10.1016/j.cognition.2010.11.015
19. E. F. Redish, In E. F. Redish, M. Vicentini, (Eds.): Proceedings of the international school of physics, "Enrico Fermi" course CLVI, IOS Press, Amsterdam, **2004**
20. G. Gigerenzer, W. Gaissmaier, *Annu. Rev. Psychol.* **2011**, *62*, 451–482. **DOI:**10.1146/annurev-psych-120709-145346
21. M. Ugras, *J. Baltic Sci. Educ.* **2018***, 17*, 343–356. **DOI:**10.33225/jbse/18.17.356
22. N. Graulich, *J. Chem. Educ.* **2014***, 92,* 205–211. **DOI:**10.1021/ed500641n
23. S. A. Sloman, *Psychol.Bull.* **1996**, *119*, 3–22. **DOI:**10.1037/0033-2909.119.1.3
24. J. S. B. T. Evans, Psychon. Bull. Rev. **2006**, *13*, 378–395. **DOI:**10.3758/BF03193858
25. J. S. B. T. Evans, *Annu. Rev. Psychol.* **2008***, 59*, 255–278. **DOI:**10.1146/annurev.psych.59.103006.093629
26. K. E. Stanovich, R. F. West, *Behav. Brain Sci.* **2000***, 23*, 645–726. **DOI:**10.1017/S0140525X00003435
27. J. R. Maeyer, *Common-se nse chemistry: the use of assumptions and heuristics in problem solving.* Ph. D. Thesis. Arizona: University of Arizona. **2013.**
28. D. Kahneman, S. Frederick, Representativeness Revisited: Attribute Substitution in Intuitive Judgment. Cambridge University Press, Cambridge, **2002.** **DOI:**10.1017/CBO9780511808098.004
29. L. K. McClary, V. Talanquer, *Int. J. Sci. Educ.* **2011***, 33,* 1433–1454. **DOI:**10.1080/09500693.2010.528463
30. A. K. Shah, D. M. Oppenheimer, *Psychol. Bull.* **2008**, *134*, 207–222. **DOI:**10.1037/0033-2909.134.2.207
31. H. A. Simon, *Annu. Rev. Psychol.* **1990**, *41*, 1–19. **DOI:**10.1146/annurev.ps.41.020190.000245
32. P. M. Todd, G. Gigerenzer, *Behav. Brain Sci.***2000***, 23*, 727–741. **DOI:**10.1017/S0140525X00003447
33. N. Graulich, H. Hopf, P. R. Schreiner, *Chem. Eur. J.* **2011***, 17,* 30–40. **DOI:**10.1002/chem.201002370
34. N. Graulich, H. Hopf, P. R. Schreiner, *Chem. Asian J.* **2011***, 6,* 3180–3188. **DOI:**10.1002/asia.201100110
35. M. M. Cooper, L. M. Corley, S. M. Underwood, *J. Res. Sci. Teach.* **2013***, 50*, 699–721. **DOI:**10.1002/tea.21093
36. M. C. Connor, S. A. Finkenstaedt-Quinn, G. V. Shultz, *Chem. Educ. Res. Pract.* **2019***, 20*, 522–541. **DOI:**10.1039/C9RP00033J
37. G. O. Karakoyun, E. Asiltürk, *J. Sci Learning*, **2020**, *4*, 50–60. **DOI:**10.17509/jsl.v4i1.23737
38. N. Didis, O. Ozcan, A. Abak, *Hacettepe University J. Educ.* **2008**, 34, 86–94.
39. M. Wihlborg, *High. Educ. Res. Dev*. **2004**, 23, 433–453. **DOI:**10.1080/0729436042000276459
40. J. Maeyer, V. Talanquer, *Sci. Educ.* **2010***, 94,* 963–984. **DOI:**10.1002/sce.20397
41. Muntholib, J. Mayangsari, Y.N. Pratiwi, M. Muchson, R. Joharmawan, Yahmin, S. Rahayu, First International Conference on Science, Mathematics, and Education, (ICoMSE 2017): Advances in Social Science, Education and Humanities Research, Malang, Indonesia, 2017, Indonesia, **2018**, pp. 251–268.
42. H. Pan, L. Henriques *Sch. Sci. Math.* **2015**, *115*, 237–243. **DOI:**10.1111/ssm.12124
43. I. Cetingul, O. Geban, *Hacettepe University J. Educ.* **2011**, *41*, 112–123.

44. B. Ross, *High School Students' Concepts of Acids and Bases*, Master Thesis. Kingston, Ontario, Canada: Queen's University, **1989**.
45. B. Ross, H. Munby, *Int. J. Sci. Educ.* **1991**, *13*, 11–23. **DOI:**10.1080/0950069910130102
46. K. Y. Hoe, R. Subramaniam, *Chem. Educ. Res. Pract.* **2016**, 17, 263–282. **DOI:**10.1039/C5RP00146C

Povzetek

Namen te raziskave je proučiti učinke desetih hevristik, ki jih je predlagal Talanquer, na postopke sklepanja kandidatov za učitelje naravoslovja na temo »kemijska struktura – razmerje kislost/bazičnost«. V tej fenomenografski raziskavi so bili v spomladanskem semestru študijskega leta 2018–2019 opravljeni razgovori s 30 bodočimi učitelji, ki so bili vpisani v program za izobraževanje na področju naravoslovja, Fakulteta za izobraževanje Univerze Firat. V prvi fazi dvostopenjskega intervjuja so bili udeleženci pozvani, naj nekatere kemijske spojine razvrstijo glede na njihovo naraščajočo kislostjo, v drugi fazi pa nekatere kemijske spojine glede na njihovo naraščajočo bazičnost. V intervjujih so bili udeleženci pozvani tudi, da podrobno pojasnijo razloge za uvrstitev. Od odgovorov, ki so jih na vprašanja dali udeleženci, so dobili šest različnih vzorcev odgovorov glede jakosti kislin ter pet različnih vzorcev odgovorov glede jakosti baz. Ugotovljeno je bilo, da vseh deset hevristik vpliva na razmišljanje udeležencev, zaradi učinkov hevristike pa študentje na splošno namesto znanstvenega argumentiranja uporabljajo bližnjice. Poleg tega je ta študija razkrila, da čeprav ni bila vključena v model, ki ga je predlagal Talanquer, hevristični periodični trendi vplivajo tudi na razmišljanje udeležencev o »razmerju kemijska struktura – kislost/bazičnost«.