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Logical Thinking Abilities Scale: Reliability and Validity Studies

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Abstract This study aims to develop logical thinking skills scale for science teacher candidates. The method of the study is the scale development model, which is the sub model of the exploratory pattern in the mixed method. The scale was prepared by referring to Lawson's Classroom Test of Science Reasoning (1978). In the study, the item pool was created first. The questions were prepared from the topics in the General Chemistry Laboratory Applications course from six sub-dimensions. Taking the expert opinion, necessary corrections were made and a trial form with 13 multiple choice and two open-ended questions were prepared. Multiple choice questions consist of two stages. In the first stage, it is requested to find the right option regarding the item (group A questions), and in the other stage, the reason for the answer (group B questions) is requested. The trial form was applied to 142 science teacher candidates. Multiple choice questions were analyzed with the Test Analysis Program (TAP). Open-ended items were rearranged receiving expert opinion in the light of the data obtained by scoring. At the end of the analysis, the 12th item was removed from the scale. As a result of the analysis, it was observed that the average difficulty and discrimination indices of the A and B group items were high. As a result of these findings, it can be said that the logical thinking abilities scale developed for prospective science teachers is appropriate in terms of reliability and validity.

Keywords Logical Thinking Skills Scale, Science Education, Science Teacher Candidates, Scale Development

1. Introduction

Individuals live by interacting with their environments with an instinct of curiosity at every moment of their lives. Individuals who seek solutions to the problems they encounter during an interaction need to define events, obtain necessary information and produce solutions in order to solve these problems [1].

Emotional skills as well as cognitive skills are effective on students' academic achievement. One of the cognitive skills that have an impact on students' academic achievement is logical thinking skill. Logical thinking can be defined as the individual reaching the necessary principles and laws by solving a problem with different operations [2].

Individuals with logical thinking abilities can see the relationships between concepts while solving the problems they encounter in daily life. They can evaluate their thoughts, knowledge and experiences by establishing a cause-effect relationship. This will contribute to high-level learning [1,3].

According to Piaget, logical thinking starts with a stage of concrete processes and continues with a stage of abstract processes. The cognitive development level of individuals also affects their problem-solving skills. Cognitive development stages are universal, that is, they are common to all individuals. Individual differences will occur in the physical and cognitive fields as the genetic characteristics of the individuals, the environmental factors affecting these characteristics and the experiences of the individual differ. This causes differences in the decision-making processes of individuals and their logical thinking abilities [2,4].

The field of science requires abstract thinking ability. Therefore, logical thinking has an important place in sciences as well as in other disciplines. The ability to think logically is very important in the process of learning scientific concepts. Because if a certain concept is not fully learned, it will be difficult to understand the related concepts or facts. Logical thinking affects students' understanding as well as their attitudes towards science [2,5].

The aim of education is to educate individuals who are curious, experimenting, researching, discovering, querying and questioning problems from different angles. Thus, problem solving and logical thinking skills are cognitive skills that should be addressed at every stage of the education process [6]. Logical thinking skills are a factor affecting academic success. In order to develop students' logical thinking skills, their problem solving, creative thinking and critical thinking skills should be developed. For this, students should be provided with research and application-based learning environments. Appropriate assessment and evaluation approaches should be used [4]. Logical thinking skill should not be considered as a stand-alone course, but should be included in the whole curriculum with an interdisciplinary logic. Suitable teaching methods for logical thinking skills should be chosen and applied [5].

It is important to investigate the factors that affect logical thinking skills and apply the results in education [7]. When the literature is examined, it is seen that there are studies that analyse the relationship between logical thinking abilities and academic success, critical thinking tendencies, attitude towards course, gender, the field of education and parents' level of education. While there is a high level of positive correlation between logical thinking abilities and academic achievement, there is a low level of positive relationship between logical thinking abilities and critical thinking tendencies [8]. When we look at the relationship between logical thinking abilities and attitude towards the course, it is seen that there is a low level of positive correlation between prospective teachers' attitudes towards science course and logical thinking abilities [9]. There was no significant difference between logical thinking skills and parents' education levels [7].

When studies examining the level of logical thinking abilities are analyzed, it is seen that the results are different. When the grades of prospective science teachers and classroom teachers received from the test are analyzed, it is seen that they are at the level of “Students tested their hypotheses in a contradictory way in observable events.”, which is referred to as low level I [7]. While it is seen that prospective elementary mathematics and science teachers have high levels of logical thinking. When the studies are examined, it is seen that logical thinking abilities are affected by different variables, and there is a positive relationship between academic achievement and attitude towards science [10]. A similar result exists between logical thinking skills and the gender variable. In some studies, it is seen that there is no significant difference between logical thinking skills and gender [9,11]. On the other hand, in some studies, there is a significant difference between logical thinking skills and gender [7,10,12].

In educational sciences, there are also studies that examine the meaningful difference between logical thinking skills and the field of study [7,10,12].

In educational sciences, it is seen that there are scales available to measure logical thinking abilities. The Logical Thinking Group Test, which was developed by Roadrangka, Yeany, and Padilla (1982), was translated into Turkish by Aksu, Berberoğlu and Paykoç in 1990. It is stated that the test has the validity and reliability to measure the logical thinking abilities of students from 6th grade to the university [13].

Logical Thinking Test was developed by Tobin and Capie (1981) and adapted to Turkish by Geban, Aşkar and Özkan in 1992. 10 questions in the test were used to present five reasoning situations (proportional reasoning, control variables, probability reasoning, relational and combinational reasoning). The scale was applied to high school students [12].

The questions in the Logical Thinking Ability Scale were prepared by adapting from Lawson’s Classroom Test of Science Reasoning (1978). The scale was translated into Turkish by Yaman and Karamustafaoğlu in 2006. Multiple-choice questions in the scale consist of subjects of Chemical Reaction, Acid-Base, Isotope and Ion. The measurement tool, which has a total of 16 questions, includes 4 questions from each subject. The scale was applied to prospective teachers [14].

Rational Experiential Inventory (REI) was developed by Pacini and Epstein (1999). The scale was translated into Turkish by Türk and Artar (2014). The scale was applied to high school students [15].

Scientific Reasoning Test was developed by Lawson in 1978 and adapted to Turkish by Yüzüak (2012). The scale was applied to prospective teachers [16]. Apart from these scales, there are other scales and tests developed to measure the logical thinking abilities in the field of mathematics. For Logical Thinking Abilities Scale, the literature has been analyzed, and a new scale has been developed by writing the items related to geometry knowledge of prospective mathematics teachers [17]. Mathematical Processing Instrument (MPI) developed by Suwarsono (1982) was adapted to Turkish by Hacıömeroğlu and Hacıömeroğlu (2013) [18].

Mathematical Processing-Instrument for Calculus (MPI-C) was developed by Hacıömeroğlu and Chicken (2011) and adapted to Turkish by Hacıömeroğlu, Hacıömeroğlu, Bukova-Güzel and Kula (2014). MPI-C was developed to examine individuals' visual, analytical and harmonic solution preferences for derivative and integral questions [19].

Studies in educational sciences reveal the role of logical thinking skills in education and their importance on student achievement. These results make it necessary to develop logical thinking skills [4]. At the same time, logical thinking is a skill that should be acquired by prospective teachers [14]. In educational science although there are scales that measure logical thinking skills (Logical Thinking Ability Scale- Yaman & Karamustafaoğlu, 2006; Lawson's Classroom Test of Science Reasoning- Yüzüak, 2012), there are not any scales that directly measure the logical thinking abilities of prospective science teachers. Therefore, to fill the gap in the field, a scale that aims to measure the logical thinking skills of prospective science teachers was developed in this study by referring to Lawson's Classroom Test of Science Reasoning (1978).

2. Method

The study of developing a logical thinking abilities scale is the instrument development model study, which is the sub-model of the explanatory pattern in the mixed method. The explanatory pattern is an approach consisting of two stages. While the first stage consists of the qualitative part, the second stage is shaped according to the data obtained from the quantitative part [20]. In the qualitative dimension of this study, the item pool was created, expert opinion was obtained, the items were corrected, and the trial form was created. In the quantitative dimension of the study, the trial form was applied and the scale was finalized according to the obtained data.

The samples of this study are 142 prospective science teachers who are 2nd, 3rd and 4th grade students at the science teaching department. This scale aims to measure the logical thinking.

In this study, firstly, an item repository was prepared from the topics on which experiments were conducted within the scope of the General Chemistry Laboratory Applications course. Item repository consists of multiple-choice and open-ended items. Multiple-choice items consist of two stages. While in the stage that follows the question, the right answer to the question is asked (group A questions), in the other stage, the reason for the choice of the given answer is asked (group B questions). Therefore, multiple-choice items consist of two questions within themselves.

Table 1. Repository of Items Submitted for Expert Opinion

Sub-dimensions	Item Type	Number of Items
Protection of mass and volume	Multiple-choice	3
Proportional reasoning	Multiple-choice	2
Control of variables	Multiple-choice	2
Probabilistic thinking	Multiple-choice	3
Correlational thinking	Multiple-choice	3
Hypothetical thinking	Open ended	2
Total		15

The expert opinion examined the suitability of the items in terms of the relevant sub-dimension, the grade level and the scientific perspective. In line with the expert opinion, the necessary corrections were made to the items and a test form was prepared. The test form was applied to 142 prospective teachers. It was seen that 15 items were answered in approximately 35 minutes.

Multiple-choice items were marked on the optical form, while open-ended items were answered on the form. Group A questions and Group B questions are individually marked on the optical form. The obtained data were analyzed with Test Analysis Program (TAP V.16.11.13). Item difficulty and discrimination indices were calculated only for multiple-choice items. Open-ended items were graded and rearranged in the light of the obtained data in accordance with the expert opinion.

As a result of the analysis, in the selection from the item depository, the item difficulty and discrimination indices that are accepted in the field were taken into consideration in accordance with TAP warnings on the removal of some of the items. Item difficulty indices used in the field are given in Table 2 [21].

Table 2. Item Difficulty Indices (p)

Difficulty Index (P_j)	Assessment
0-0.30	It is a very difficult item.
0.30-0.70	They are suitable to include in the test. The difficulty is at an acceptable level.
0.85-1	They are very easy items.

The required values of the discrimination index of an item in the field are given in Table 3[21,22].

Table 3. Item Discrimination Indices (r_{jx})

Discrimination Index (r_{jx})	Assessment
0.19 and below	Very weak item; they should be corrected or removed.
0.20-0.29	The item is acceptable.
0.30-0.39	It is a very good item.
0.40 and above	It is a very good item.

3. Findings

The data set obtained in the test form prepared to measure the logical thinking abilities of the prospective science teachers was analyzed. In the data collection tool, there are 13 questions in both A and B groups, and since each question is 1 point, the highest score that can be obtained is 13 and the lowest score is 0.

When Table 4 is examined, it is seen that there is a warning by the TAP to remove item 12 in both A and B question groups. Based on this, item 12 was removed, and the analysis continued.

When Table 5 is examined, it is seen that there are no items below 0.20 in terms of difficulty and discrimination in both A and B question groups.

Table 4. Item Analysis Results (Analysis 1)

Group A Questions						Group B Questions					
Question	N	P_j	r_{jx}	S^2	Sd	Question	N	P_j	r_{jx}	S^2	Sd
1	118	0.83	0.27	0.14	0.375	1	110	0.77	0.40	0.177	0.420
2	82	0.58	0.26	0.24	0.493	2	85	0.6	0.56	0.240	0.489
3*	61	0.43	0.39	0.24	0.495	3	65	0.46	0.55	0.248	0.498
4	106	0.75	0.3	0.18	0.433	4	105	0.74	0.23	0.192	0.438
5	81	0.57	0.34	0.24	0.495	5	85	0.6	0.44	0.240	0.489
6	79	0.56	0.64	0.24	0.496	6	58	0.41	0.48	0.241	0.491
7	34	0.24	0.24	0.18	0.427	7	33	0.23	0.29	0.177	0.420
8	45	0.32	0.52	0.21	0.466	8	96	0.68	0.38	0.217	0.466
9	64	0.45	0.53	0.24	0.497	9	69	0.49	0.46	0.249	0.499
10	51	0.36	0.52	0.23	0.480	10	71	0.5	0.54	0.250	0.500
11	85	0.6	0.48	0.24	0.489	11	106	0.75	0.37	0.187	0.433
12*	95	0.67	0.23	0.22	0.470	12*	26	0.18	0.04	0.147	0.384
13	42	0.3	0.21	0.21	0.458	13	47	0.33	0.29	0.221	0.470

* Item subject to a warning by TAP

Table 5. Item Analysis Results (Analysis 2)

Group A Questions						Group B Questions					
Question	N	P_j	r_{jx}	S^2	Sd	Question	N	P_j	r_{jx}	S^2	Sd
1	118	0.83	0.23	0.141	0.375	1	110	0.77	0.38	0.177	0.420
2	82	0.58	0.24	0.243	0.493	2	85	0.6	0.56	0.240	0.489
3	61	0.43	0.34	0.245	0.495	3	65	0.46	0.55	0.248	0.498
4	106	0.75	0.27	0.187	0.433	4	105	0.74	0.22	0.192	0.438
5	81	0.57	0.26	0.245	0.495	5	85	0.6	0.45	0.240	0.489
6	79	0.56	0.45	0.246	0.496	6	58	0.41	0.51	0.241	0.491
7	34	0.24	0.25	0.182	0.427	7	33	0.23	0.26	0.177	0.420
8	45	0.32	0.47	0.217	0.466	8	96	0.68	0.43	0.217	0.466
9	64	0.45	0.48	0.247	0.497	9	69	0.49	0.43	0.249	0.499
10	51	0.36	0.48	0.230	0.480	10	71	0.5	0.52	0.250	0.500
11	85	0.6	0.35	0.240	0.489	11	106	0.75	0.38	0.187	0.433
13	42	0.3	0.2	0.210	0.458	13	47	0.33	0.3	0.221	0.470

In the analysis of all A group questions (Table 6), it is seen that the average difficulty index is Pj= 0.498, the average discrimination index is rjx= 0.343 and the internal consistency coefficient is KR-20 = 0.406.

Table 6. Group A Test Analysis Results

Number of questions	$\bar{x}$	S^2	Sd	P_j	r_{jx}	KR-20
12	49.8	4.196	2.049	0.498	0.334	0.406

Similarly, in the analysis of group B questions (Table 7), it is seen that the average difficulty index is P_j= 0.546, the average discrimination index is$_{jx}$= 0.415 and the internal consistency coefficient is KR-20=0.471.

Table 7. Group B Test Analysis Results

Number of questions	$\bar{x}$	S^2	Sd	P_j	r_{jx}	KR-20
12	54.6	4.656	2.158	0.546	0.415	0.471

Since the items in the test were divided into group A and B questions, the correlation of the scores between the two groups was calculated. In the result that was obtained by using the Spearman-Brown formula, the internal consistency coefficient for the entire test was calculated as r_x= 0.962.

4. Conclusions and Interpretation

The test form which was prepared to measure the logical thinking abilities of prospective science teachers was applied to prospective teachers and the obtained data were analyzed. With the analysis made after the removal of item 12 (Table 4) with the recommendation of TAP, it was seen that the difficulty and discrimination values of all items were higher than 0.20 (Table 5). The conclusively decided test includes 12 multiple-choice and 2 open-ended items.

Regarding the studies carried out for the reliability and validity of this study, which aims to measure the logical thinking abilities of prospective science teachers, KR-20 values calculated for group A and group B questions are 0.406 and 0.471, respectively. KR-20 is based on the assumption that each item in the test measures the same value, that is, the items are homogeneous [23]. When the scale is analyzed, it is seen that multiple-choice items consist of 5 different sub-dimensions and different topics. In this case, it can be said that the items are not homogeneous and therefore KR-20 values are low. On the other hand, the internal consistency coefficient between groups A and B questions was calculated using the Spearman – Brown formula and r_x= 0.962 internal consistency coefficient was obtained. This coefficient shows that the internal consistency coefficient of the scale is high in terms of reliability.

Applying for expert opinion during the scale development stages and making necessary arrangements in the item repository in line with the obtained feedback may mean that both the content validity and the face validity are provided. In addition, item 12, which was removed from the item repository after the analysis of all items, is an item of "Probabilistic Thinking" sub-dimension. When Table 1 is examined, it can be seen that one removed item does not affect the validity of the content since there are 3 items in the relevant sub-item item repository.

In terms of the construct validity, for group A items, the average item difficulty index is ($P_{j=}$0.498) and the average discrimination index is (r_{jx}= 0.334), and for group B items, the average item difficulty index is ($P_{j=}$0.546) and the average discrimination index is (r_{jx}= 0.415), which show that the construct validity levels are at the desired level.

As a result of these findings, it can be said that the logical thinking abilities scale developed for prospective science teachers is appropriate in terms of reliability and validity.

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