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Mathematicians' Individual Criteria for Accepting Theorems and Proofs: The Sample of Turkey

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Abstract: The aim of this study is to research the criteria employed by mathematicians when accepting the correctness of theorems in their research areas, correctness of theorems in other research areas in which they are not expert, and the correctness of a theorem and its proof in their reviewing process of a research article. The study was conducted with 102 mathematicians who volunteered to participate in the research. State universities located in Turkey were considered in selecting the participants, and the researcher selected the academicians who were working at the department of mathematics in these universities. Twenty-six of these universities could be included in the research since the research was conducted according to the principle of voluntariness. The data were obtained via Survey on Accepting Mathematical Theorems and Proofs (SAMTP). Descriptive and predictive statistics methods were used in analyzing the data obtained. In view of the research, it was found that mathematicians had such criterion that they had to verify the result through their own examinations in order to accept correctness of theorems and their proofs related to both and other research areas. Furthermore, it was observed that the mathematicians' criteria are not different in the reviewing processes.

Keywords: Mathematicians individual criteria, theorem, proof

Matematikçilerin Teoremlerin ve İspatların Kabulü İçin Kişisel Kriterleri: Türkiye Örneği

Öz: Bu çalışmada, matematikçilerin uzman oldukları araştırma alanlarına yönelik teoremlerin doğruluğunu, uzman olmadıkları diğer araştırma alanlarındaki teoremlerin doğruluğunu ve bir araştırma makalesindeki hakemlik süreçlerinde bir teoremin ve ispatının doğruluğunu kabul ederken hangi kriterlere sahip olduklarının araştırılması amaçlanmıştır. Çalışma, 26 farklı üniversitede matematik bölümlerinde görev yapan ve araştırmaya katılmaya gönüllü olan 102 matematikçi ile yürütülmüştür. Veriler, Matematiksel Teoremlerin Kabulü ve İspat Anketi (MTKİA) ile elde edilmiştir. Elde edilen verilerin analizinde betimsel ve kestirimsel istatistik yöntemleri kullanılmıştır. Araştırma sonucunda matematikçilerin hem uzman oldukları araştırma alanları ile ilgili hem de diğer araştırma alanları ile ilgili teoremlerin ve ispatlarının doğruluğunu kabul etmeleri için kendi incelemeleri ile sonucu doğrulamaları gerektiği kriterlerinin olduğu tespit edilmiştir. Ayrıca matematikçilerin hakemlik süreçlerindeki kriterlerin de farklı olmadığı görülmüştür.

Anahtar Kelimeler: Matematikçilerin kişisel kriterleri, teorem, ispat

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The most common mathematical practice is to take an interest in proofs of theorems. Writers dealing with mathematics try to form proofs and meticulously write these proofs. Readers try to verify and understand the proofs performed by other mathematicians. Peer reviewers and journal editors try to evaluate the value and interestingness of proofs. Teachers try to explain proofs for new beginners. Why do mathematicians take such a profound interest in proofs? Or to formalize it more directly, why do we prove theorems (Pelc, 2009)? The clearest answer that can be given to this question is that we perform proof in order to convince ourselves and others of the correctness of theorems (Harel & Sowder, 1998; Rav, 1999). Moreover, proof is used (i) to verify a result; (ii) to convince others and to communicate; (iii) to discover a result; and (iv) to systemize results within a deduction system (Almeida, 2001). On the other hand, Rav (1999) defined proof as follows: proof is to mathematicians what experimental procedures are to scientists who study an experimental science. Thanks to proof, mathematicians learn new ideas, new concepts and new strategies in their studies. Thus, they form a study area for themselves, and they develop this study area (Rav, 1999). However, reviewing the acceptance of new mathematical results is a considerably complicated and difficult research area as a part of mathematical researches. This research area set forth that the objective criteria that are used in evaluating old ideas are inadequate (Heinze, 2010).

Upon examining the history of mathematics, it is observed that the opinions arguing that mathematics is absolutely correct have been interrupted by the development of mathematics in the last century and the failures of foundationalist approaches in depicting this development. Discovery of non-Euclidean geometries, developments in set theory and the concept of infinity, and phenomena such as the use of computers in mathematical proof shook the foundations of some established understandings related with the nature of mathematics (Baki, Bütün & Karakuş, 2010). Mathematics is a product of social processes especially in accordance with the quasi-experimentalism movement that is among the movements in the philosophy of mathematics (Ernest, 2004; Lakatos, 1976). According to this movement, mathematics is defined as a thing that is performed by mathematicians, and this movement accepts that there may be flaws in mathematics as there can be in any human activity or product (Baki, 2008). Especially in the last century, with his theorems, Gödel did not allow for actualizing Hilbert's consistency and completeness idea that the correctness of mathematical results can be determined via an algorithm (Gödel, 2010; Nesin, 2008; Yıldırım, 1996). Similarly, with the paradoxes that he asserted, Russell stroke a major blow against the foundations of Frege's book entitled "Basic Laws of Arithmetic" in which he aimed to base mathematics on sound foundations with the help of set theory. Frege said, "Arithmetic is stumbling", and stated his disappointment when he learned about the Russell's paradox as follows:

> *For a scientist, nothing can be more unpleasant than the sudden collapse of the foundations of a study that he completed. A letter that I received from Bertrand Russell created such unpleasantness for me as my work was about to be distributed from the publishing house (Yıldırım, 1996).*

How do mathematicians become sure of the correctness of the results that they reached in mathematics that is not based on observation and experiment? This question can be asked more generally as follows: Which criteria do the scientists dealing with mathematics consider while deciding on the correctness of a result? It is considerably difficult to find answers to all these questions, but at least one can determine the criteria formed by mathematicians among themselves to reach correct results. Hanna (1983) speaks of a number of criteria important for assessing results. She states that most mathematicians accept a new theorem when some combinations of the following factors are present. These are:

1. When they understand the theorem by concretizing it with concepts in its logical antecedents and implications,

2. When the theorem is significant enough to have implications in one or more branches of mathematics (and is thus important and useful enough to warrant detailed study and analysis),

3. When the theorem is consistent with the body of accepted mathematical results,

4. When the author has an unimpeachable reputation as an expert in matters about the theorem,

5. When they encounter (rigorous or otherwise) convincing mathematical argument for the theorem (Heinze, 2010).

Stating that there is no empirical data concerning mathematicians' criteria for evaluating and accepting theorems, Heinze (2010) conducted an empirical study. In the study, an examination was performed in order to find the criteria considered by the mathematicians for accepting theorems in their own research areas, for accepting theorems in other research areas in which they are not an expert, and for accepting the correctness of a theorem and its proof in their reviewing process of a research article. The data of the research were obtained via a survey that was formed by the writer. Forty mathematicians working in a university located in Germany participated in the research. In view of the research, it was found that while accepting new proofs, mathematicians considered peer-reviewed journals, their own examinations, the frequency of use, and the fact that no contradictory idea has been claimed even if it was published a long time ago.

When one examines the literature on how mathematicians accept proofs of the theorems for which they did not form a proof, a shortage existing in this field catches one's attention. Thus, the aim of this study is to research the criteria employed by mathematicians when accepting correctness of theorems, for which they did not form a proof, in their own research areas and other research areas, and how they decide when accepting the correctness of a theorem and its proof in their reviewing process. By doing so, a guide is created to eliminate doubts on the trueness of mathematical knowledge that remained from past to present, and to determine common criteria for evaluating the proofs of theorems among mathematicians.

Method

This research was conducted using the survey model that is among the descriptive research designs. The survey method is used in studies that attempt to describe what situations, objects, beings, organizations, groups, and conditions belonging to various areas are, and to explain them with all their properties. Through this method, an attempt is made to describe and set forth current circumstances, conditions and properties on the entire universe or a group taken from that universe in order to pass a general judgment on the universe in a universe that is composed of many numbers of elements (Cohen & Manion, 1997; Karasar, 2009).

Research Group

The research was conducted with 102 academicians who were working in 26 state universities located in Turkey and who volunteered to participate in the research. State universities located in Turkey were considered in selecting the participants, and the researcher selected the academicians who were working at the department of mathematics in these universities. Twenty-six of these universities could be included in the research since the research was conducted according to the principle of voluntariness. It can be stated that the research has an exploratory feature in some way since it was not known by whom the surveys sent in the research were answered (Heinze, 2010). Distribution of the academicians who participated in the research by university and title is given in Appendix 1.

Distribution of the academicians who participated in the research by field of study is given in Table 1.

Tablo 1.
Distribution of the mathematicians by field of study

Research Area	**Academic Titles**					
	Professor	**Associate Professor**	**Assistant Professor**	**Doctor**	**Doctoral Student**	**Total**
Analysis and Function Theory	6	4	6	4	6	26
Geometry	4	4	3	3	10	24
Topology	1	2	3	1	2	9
Algebra and Number Theory	1	3	5	2	5	16
Applied Mathematics	2	5	3	1	8	19
Fundamentals of Mathematics and Mathematical Logic	-	1	1	-	3	5
Other	1	1	-	-	1	3

Data collection

The data of the study were obtained via Survey on Accepting Mathematical Theorems and Proofs (SAMTP) that was developed by Heinze (2010). SAMTP is composed of three sections. In the first section, there is a Likert type questionnaire composed of ten items used to discover in which conditions mathematicians accept a theorem of which they did not find proof to be correct during their daily mathematical studies. This questionnaire is composed of two sections; namely, mathematicians’ own research areas and other research areas. In the second section, mathematicians are asked to assume that they are peer reviewers, and a Likert type questionnaire composed of six items is used to discover in which conditions mathematicians accept a theorem and its proof to be correct when reviewing an article. The third section is about mathematicians' personal information (academic title, research area) and their opinions on the study. The following procedure was followed up in adapting the survey into Turkish.

First of all, permission was taken from the developer of the survey to translate it into Turkish. Then, survey items were translated into Turkish independently by three people. Then, the researcher compared these three translations, and selected the appropriate translations. Following this stage, five language experts on English were asked to grade translation appropriateness for each items using English-Turkish compatibility grading form. Forms were filled out independently by the experts. While grading the items, experts stated their suggestions, if any, on the form. Considering the suggestions of the experts, the researcher made a number of changes in Turkish translation.

Following the English-Turkish compatibility stage, Turkish language experts graded the levels of appropriateness to Turkish grammar and understandability of each item in the Turkish form. As in the translation appropriateness stage, revisions were made to the Turkish translation considering the suggestions of the experts.

Five language experts on English translated the Turkish items of the survey into English. Then, the translated items were compared with the original English items. Five language experts on English participated in this stage, and the meaning appropriateness of the original items and the translated items was tested. Thus, the translation and language validity study of the survey was completed, and the Turkish form of the survey was finalized.

SAMTP, the Turkish form of which was finalized, was sent via email to 600 mathematicians working in 100 different universities designated by the researcher. Mathematicians were given a period of two months in which to return their completed forms. At the end of this period, data of 102 mathematicians from 26 different universities were obtained.

Analysis of the data

Descriptive and predictive statistics methods were used in analyzing the data of the research. Likert-type items in the SAMTP were graded as "Always= 4", "Frequently=3", "Sometimes=2" and "Never=1". Statistical Package for the Social Sciences (SPSS 16 for Windows) was utilized in analyzing the data. Among the participants of the research, doctoral students and those who had doctoral degrees were classed as young mathematicians whereas professors, associate professors and assistant professors were classed as senior mathematicians. This classification was performed considering the academic hierarchy of the universities in our country. Considering this classification, the answers given by young mathematicians and senior mathematicians to survey items were statistically analyzed.

Findings

This section of the research covers the findings obtained from the answers that were given by mathematicians to survey items. The answers given by mathematicians to survey items were transferred into graphs and presented. Figure 1 shows the criteria along with their means that made young mathematicians and senior mathematicians accept the correctness of a theorem related to their own research areas.

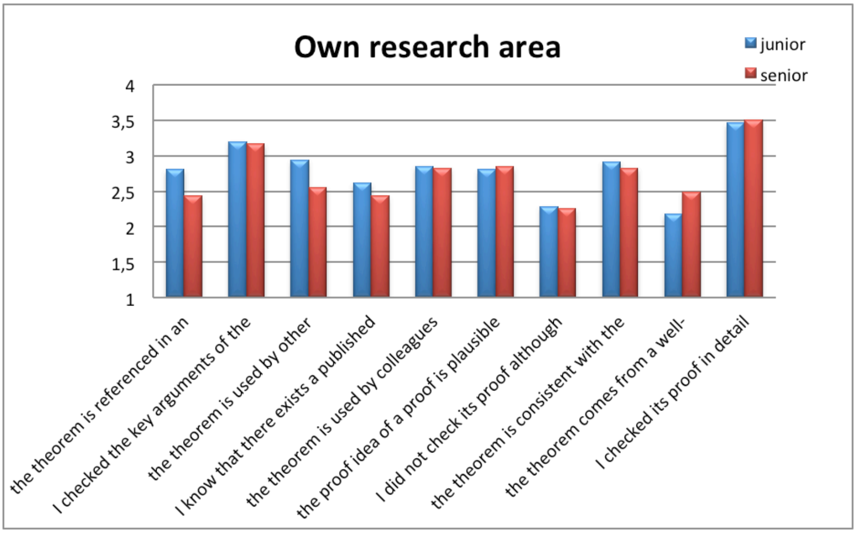


Figure 1. Criteria of junior and senior mathematicians for the acceptance of new theorems in their own research area

According to Figure 1, it was found that there was a statistically significant difference in favor of young mathematicians in the first and the third items between the criteria of young mathematicians and senior mathematicians for accepting a new theorem related to their own research areas. According to this finding, it can be stated that compared to their senior colleagues, young mathematicians placed higher values on the criteria "if the theorem is referenced in an article in a peer-reviewed journal" and "if the theorem is used by other mathematicians (in their speeches, publications, etc.)" ($p<0.05$). However, in other items of the survey, it was found that the answers of young mathematicians and senior mathematicians were parallel and did not vary statistically.

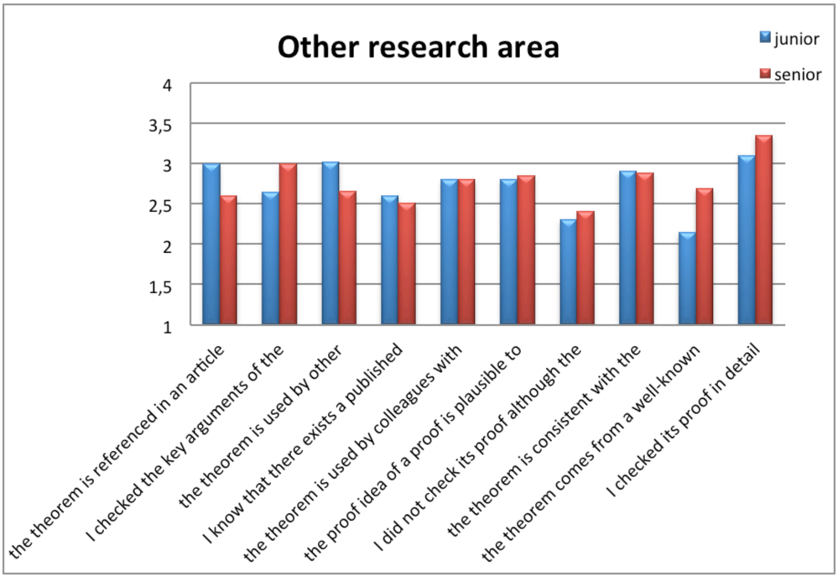
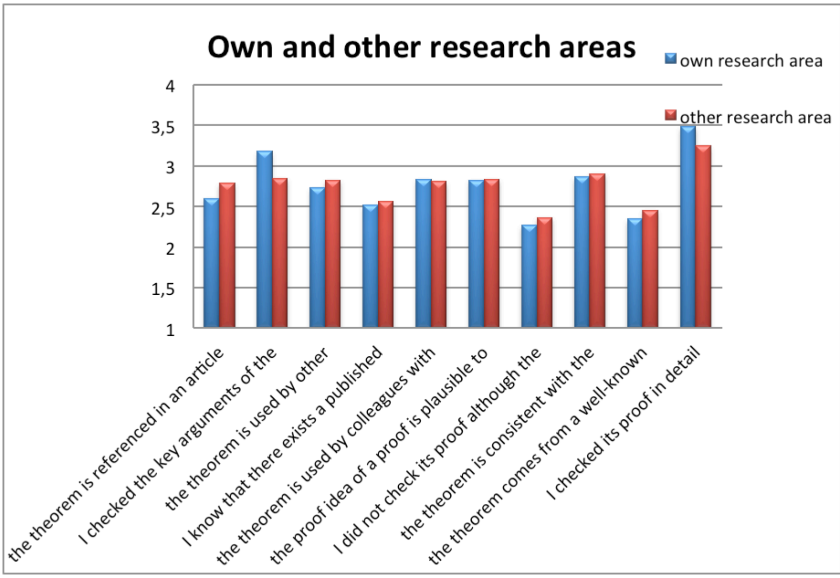


Figure 2. Criteria of junior and senior mathematicians for the acceptance of new theorems in their other research area

It was found that there was a statistically significant difference in favor of young mathematicians in the first and the third items whereas there was a statistically significant difference in favor of senior mathematicians in the ninth item between the criteria of young mathematicians and senior mathematicians for accepting a new theorem related to research areas other than their own research areas. According to this finding, compared to their senior colleagues, young mathematicians placed higher values on the criteria "if the theorem is referenced in an article in a peer-reviewed journal" and "if the theorem is used by other mathematicians (in their speeches, publications, etc.)" in other research areas, as in their own research areas ($p<0.05$). Furthermore, it is observed that compared to their young colleagues, senior mathematicians attached importance to the criteria "if the theorem comes from a well-known and respected colleague" ($p<0.05$). However, in other items of the survey, it was found that the answers of young mathematicians and senior mathematicians were parallel and did not vary statistically.



Fi**gure 3.** Criteria of mathematicians for the acceptance of new theorems in their own and in other research areas

It is observed that when mathematicians accepted a theorem related to their own research areas, they generally selected the criterion "if I checked its proof in detail" or "if I checked the key arguments of the proof". In both criteria, the mean value of mathematicians' answers was more than three. However, it can be stated that mathematicians acted more cautiously in accepting a theorem in research areas other than their own research areas. This is because only the mean value of the criterion "if I checked its proof in detail" was more than three among the criteria of mathematicians for deciding on the correctness of theorems related to other research areas. According to these findings obtained from the graph, it is observed that the mathematicians attached the highest importance to the criterion "if I checked its proof in detail". This finding shows that mathematicians think they need to examine a newly encountered theorem in detail by themselves. However, it is understood that the mathematicians did not give much credit to the criteria "if I did not check its proof although the theorem including its proof was published in a peer-reviewed journal" and "if the theorem comes from a well-known and respected colleague". This is because it is observed that the mean of the answers given by mathematicians to the related survey item was below 2.5 for both criteria.

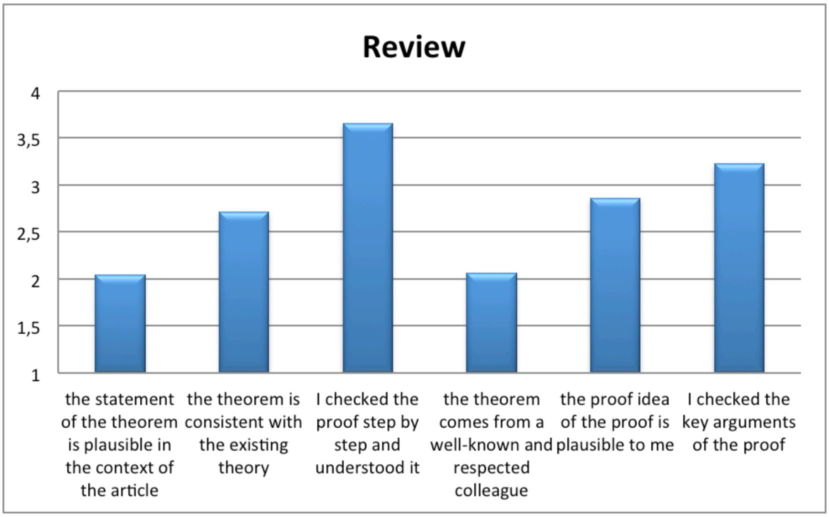


Figure 4. Criteria of mathematicians for the acceptance of new theorems when reviewing a research paper

The mean values of the criteria required by mathematicians to accept the correctness of a theorem and its proof in their reviewing process of an article in a peer-reviewed journal are given in Figure 4. Since young mathematicians' answers on their reviewing process are parallel to each other, they do not exhibit a statistically significant difference ($p>0.05$). Thus, a general evaluation was performed. It is observed that the mathematicians rather considered the criteria "if I checked the proof step by step and understood it" and "if I checked the key arguments of the proof" for accepting the correctness of a theorem and its proof in the reviewing process. On the other hand, it can be stated that the mathematicians did not give much credit to the criteria "if the statement of the theorem is plausible in the context of the article" and "if the theorem comes from a well-known and respected colleague". Therefore, it can be stated that the mathematicians generally needed to be adequately convinced of the theorems and proofs that they examined during their reviewing process.

Results and Discussion

It was observed that the most evident criteria for mathematicians in accepting the correctness of theorems related to their own research areas were the criteria "if I checked its proof in detail" and "if I checked the key arguments of the proof". This result obtained in the research shows that mathematicians initially conducted a detailed examination when accepting the correctness of a theorem and its proof that they needed to use in their studies on their own research areas. On this issue, a senior mathematician stated his opinion as follows: *"Even though the conducted study has been written by an acquaintance or a friend of mine, I check it. Of course, this is also related to the importance that you attach to the writer. Furthermore, by doing so, your respect for the study, its writer and your job transpire."* On the other hand, a statistically significant difference was found in favor of young mathematicians in the criteria "if the theorem is referenced in an article in a peer-reviewed journal" and "if the theorem is used by other mathematicians (in their speeches, publications, etc.)" between the criteria of young mathematicians and senior mathematicians for accepting the correctness of a new theorem related to their own research areas. Therefore, it can be stated that compared to their senior colleagues, young mathematicians placed a higher value on the fact that the theorem was published in a prestigious journal or used by other mathematicians. In addition to this, it was concluded that the opinions of both young mathematicians and senior mathematicians were parallel in other criteria of the survey.

It was observed that the most significant criterion for mathematicians in accepting the correctness of a theorem and its proof related to the research areas other than their own research areas was the criterion "if I checked its proof in detail". Therefore, it can be stated that the mathematicians also conducted a detailed examination when accepting the correctness of a theorem and its proof that they needed to use in other research areas, as in their own research areas. On the other hand, statistically significant differences were found in favor of young mathematicians in the criteria "if the theorem is referenced in an article in a peer-reviewed journal" and "if the theorem is used by other mathematicians (in their speeches, publications, etc.)" whereas statistically significant differences were found in favor of senior mathematicians in the criterion "if the theorem comes from a well-known and respected colleague" between the criteria of young mathematicians and senior mathematicians for accepting a new theorem related to research areas other than their own research areas. Therefore, it can be stated that compared to their senior colleagues, young mathematicians placed a higher value on the fact that the theorem was published in a prestigious journal or used by other mathematicians. On the other hand, it can be stated that compared to their young colleagues, senior mathematicians attached more importance to the fact that the theorem comes from a well-known and respected mathematician. On this issue, a senior mathematician stated his opinion as follows: *“Since we cannot check every theorem, the reputation of the institution where the publisher works and/or where it is published are also influential factors. That is because there are great differences between reputation levels of peer-reviewed journals.”*

It was observed that the criteria “if I checked the proof step by step and understood it” and “if I checked the key arguments of the proof” were the criteria considered necessary by mathematicians for accepting the correctness of a theorem and its proof in their reviewing process. Therefore, mathematicians meticulously review theorems and their proofs in the articles reviewed by them, and they need to be convinced. On the other hand, it was concluded that the opinions of young mathematicians and senior mathematicians were parallel for the criteria in the reviewing process. On this issue, a young mathematician stated his opinion as follows: *“If I review someday, I will need time, and I will try to understand transitional aspects of the proofs in the article as much as possible. I will never bestow a privilege on any name, journal or editor.”* Indeed, this opinion clearly reflects all participating mathematicians’ evaluation criteria in their reviewing processes.

In view of the research, it was found that the mathematicians had a criterion that required them to verify the result with their own examinations in order to accept the correctness of theorems and their proofs related to both their own research areas and other research areas. Furthermore, it was observed that the mathematicians’ criteria in their reviewing processes were not different. This condition supports the opinion that mathematical information can be re-examined in terms of proof and the concepts that it uses; it is open to correction; and it may err since there may be flaws in mathematics, which is a product of social processes, as there can be in any human activity or product (Ernest, 2004). Moreover, the results of the research are consistent with the result that the mathematicians prioritize their own examinations for accepting theorems and their proofs in their own research areas, in other research areas, and in their reviewing processes (Heinze, 2010).

This research presents preliminary and exploratory information regarding the criteria that mathematicians consider important for accepting new theorems and their proofs. The criteria that mathematicians consider necessary for accepting new results can be researched in prospective studies using different methods. Furthermore, more comprehensive researches can be conducted by improving the survey items used in the research and by reaching larger groups. On the other hand, the survey used in the research does not measure mathematicians' psychometric characteristics. With the help of a scale prepared for this purpose, psychometric characteristics can also be measured, and the reasons for mathematicians' opinions can be analyzed more clearly.

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APPENDIX I

Table 2.

Distribution of the mathematicians by university and title

Universities	Academic Titles					
	Professor	Associate Professor	Assistant Professor	Doctor	Doctoral Student	Total
Adıyaman University	-	1	-	1	1	3
Ağrı İbrahim Çeçen University	-	-	2	-	1	3
Bilecik Şeyh Edebali University	-	-	-	2	1	3
Bozok University	-	1	-	1	-	2
Celal Bayar University	-	-	-	-	2	2
Çanakkale Onsekiz Mart University	-	-	1	-	-	1
Süleyman Demirel University	1	-	1	-	-	2
Erzincan University	-	-	1	-	-	1
Gazi University	-	-	-	2	-	2
Gebze Institute of Technology	-	1	-	-	-	1
Kilis 7 Aralık University	-	-	1	-	-	1
Kırklareli University	-	-	1	-	1	2
Karadeniz Technical University	-	-	-	3	9	12
Muğla Sıtkı Koçman University	-	-	-	-	1	1
Nevşehir Hacı Bektaşi Veli University	-	-	-	-	1	1
Niğde University	-	-	-	-	1	1
Middle East Technical University	2	-	-	-	-	2
Ondokuz Mayıs University	-	-	-	-	1	1
Sakarya University	-	1	3	-	1	5
Selçuk University	-	-	-	-	1	1
Uludağ University	-	-	-	1	-	1
Yıldız Technical University	1	-	-	-	-	1
Gaziosmanpaşa University	2	4	5	-	8	19
Atatürk University	9	9	1	1	4	24
Ordu University	-	2	4	-	2	8
Marmara University	-	1	1	-	-	2
Total	15	20	21	11	35	102

APPENDIX 2

On the Acceptance of Mathematical Theorems and Proofs

The public image of mathematics includes the belief that mathematics is a thoroughly exact and formalistic science. Mathematicians seem to be people who do everything quite formally. In reality, however, this perception is only partially true. With this questionnaire, I would like to ask you how you – as a mathematician – really work in your everyday mathematical research.

Completing the following questionnaire will take you only a few minutes. Anonymity is assured.

1. When do you accept a mathematical theorem of which you did not find proof by yourself to be true? Please distinguish between theorems from your own research area and theorems from other research areas that you use during your everyday mathematical work

Sufficient condition for accepting a theorem. *During my everyday mathematical work I accept a theorem to be true, if…*	own research area				other research areas			
	(almost) always	**frequently**	**sometimes**	**(almost) never**	**(almost) always**	**frequently**	**sometimes**	**(almost) never**
	☐	☐	☐	☐	☐	☐	☐	☐
… the theorem is referenced in an article in a peer-reviewed journal.	☐	☐	☐	☐	☐	☐	☐	☐
… I checked the key arguments of the proof.	☐	☐	☐	☐	☐	☐	☐	☐
… the theorem is used by other mathematicians (in their speeches, publications, etc.)	☐	☐	☐	☐	☐	☐	☐	☐
… I know that there exists a published proof for a long time and there has no contradiction been found yet.	☐	☐	☐	☐	☐	☐	☐	☐
… the theorem is used by colleagues with high standards.	☐	☐	☐	☐	☐	☐	☐	☐
… the proof idea of a proof is plausible to me.	☐	☐	☐	☐	☐	☐	☐	☐
… I did not check its proof although the theorem including its proof was published in a peer-reviewed journal.	☐	☐	☐	☐	☐	☐	☐	☐
… the theorem is consistent with the existing theory.	☐	☐	☐	☐	☐	☐	☐	☐
… the theorem comes from a well-known and respected colleague.	☐	☐	☐	☐	☐	☐	☐	☐
… I checked its proof in detail.	☐	☐	☐	☐	☐	☐	☐	☐

2. Assume that you are asked to review a paper for a professional journal. Clearly, not only the relevance of the given results for the particular area of research is of interest, but also the correctness of these results. However, a detailed analysis of the proofs is time-consuming in general.

When do you accept a theorem to be true in a reviewing process?

Sufficient condition for accepting a theorem in a reviewing process. *Reviewing an article I accept a theorem to be true, if…*	**(almost) always**	**frequently**	**sometimes**	**(almost) never**
	☐	☐	☐	☐
… the statement of the theorem is plausible in the context of the article.	☐	☐	☐	☐
… the theorem is consistent with the existing theory.	☐	☐	☐	☐
… I checked the proof step by step and understood it.	☐	☐	☐	☐
… the theorem comes from a well-known and respected colleague.	☐	☐	☐	☐
… the proof idea of the proof is plausible to me.	☐	☐	☐	☐
… I checked the key arguments of the proof.	☐	☐	☐	☐

3. Please give us some data about you and your research interest:

3.1 I am…
☐ Professor ☐ Associate Professor ☐ Assistant Professor
☐ Doctor (*PhD*) ☐ Doctoral Student

3.2 To which branch of mathematics (such as calculus, algebra, geometry etc.) would you assign your research area?
☐ Analysis and Function Theory ☐ Geometry ☐ Topology
☐ Algebra and Number Theory ☐ Applied Mathematics
☐ Fundamentals of Mathematics and Mathematical Logic
☐ Other ....

Do you have remarks or comments in this context?

Thank you for your participation!