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ARAŞTIRMA MAKALESİ / RESEARCH ARTICLE

Examination of the Trends in Theses Using Eye-Tracking Technology in the Field of Mathematics Education in Türkiye *

Türkiye'de Matematik Eğitimi Alanında Göz İzleme Teknolojisi Kullanılarak Yürütülmüş Tezlerdeki Eğilimin İncelenmesi

Berna YILDIZHAN KÖKTEN **
Erhan ERTEKİN ***

Abstract

This study aims to analyze the theses conducted using the eye-tracking technology in mathematics education based on Council of Higher Education (CoHE) Theses Center. In this study, a total of 12 scientific theses, 7 of which were master's theses and 5 of which were doctoral theses, were evaluated. Data were analyzed with content analysis technique. The theses were analyzed under three headings: descriptive, methodology and topic information. The use of eye-tracking technology in mathematics education theses in Türkiye started with a master's theses in 2010. The universities that produced the most publications are Middle East Technical University and Hacettepe University. The departments that produced the most theses were Computer Education and Instructional Technology and Information Systems. While most of the master's theses were designed in accordance with the mixed research method, most of the doctoral theses were designed in accordance with the quantitative research method. In the theses conducted, mostly undergraduate and graduate students were studied.

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** Res. Asst. Dr., Necmettin Erbakan University, Ahmet Kelesoglu Faculty of Education, Department of Mathematics and Science Education, Türkiye, E-mail: byildizhan@erbakan.edu.tr, Orcid ID: 0000-0001-7233-9992.

*** Prof. Dr., Necmettin Erbakan University, Ahmet Kelesoglu Faculty of Education, Department of Mathematics and Science Education, Türkiye, E-mail: eertekin@erbakan.edu.tr, Orcid ID: 0000-0002-6466-8996.

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Applications were generally carried out with between 51-70 participants. While interviews were used in most of the master's theses, interview method was not used in all of the doctoral theses. The most preferred eye tracker was Tobii X2-60. Problem solving strategies and usability studies are the main topics studied using eye-tracking technology in mathematics education.

Keywords: Descriptive research, eye movements, eye tracking, graduate theses, mathematics education

Öz

Bu çalışma, Yükseköğretim Kurulu (YÖK) Ulusal Tez Merkezi veri tabanına dayanarak matematik eğitiminde göz izleme teknolojisi kullanılarak yürütülmüş tezleri analiz etmeyi amaçlamaktadır. Bu çalışmada, 7'si yüksek lisans 5'i doktora tezi olmak üzere toplam 12 bilimsel tez değerlendirilmiştir. Tezler sırasıyla betimsel özellikler, yöntem bilgisi ve konu bilgisi olmak üzere üç başlık altında analiz edilmiştir. Betimsel özellikler tezlerin yayınlandığı tez türü, yıl, üniversite ve bilim dalını içermektedir. Yöntem bilgisi tezlerin araştırma yöntemi, katılımcı kitlesi, örneklem sayısı, kullanılan görüşme çeşidi ve göz izleme cihazı türü gibi bilgileri içermektedir. Konu bilgisi başlığı altında ise araştırmanın hangi konu özelinde gerçekleştirildiği bilgisi yer almaktadır. Türkiye'de matematik eğitimi tezlerinde göz izleme teknolojisinin kullanımı 2010 yılında bir yüksek lisans tezi ile başlamıştır. En fazla yayın üreten üniversiteler Orta Doğu Teknik Üniversitesi ve Hacettepe Üniversitesi'dir. En fazla tez üreten bilim dalı ise Bilgisayar ve Öğretim Teknolojileri Eğitimi Bilim Dalı ve Bilişim Sistemleri Bilim Dalı'dır. Yüksek lisans tezlerinin çoğu karma araştırma yöntemine uygun olarak tasarlanmışken doktora tezlerinin çoğu nicel araştırma yöntemine uygun olarak tasarlanmıştır. Yürütülen tezlerde çoğunlukla lisans ve lisans öğrencileri ile çalışılmıştır. Uygulamalar genellikle 51-70 arasında katılımcı ile gerçekleştirilmiştir. Yürütülen yüksek lisans tezlerinin çoğunda görüşme kullanılmışken doktora tezlerinin tamamında görüşme yöntemi kullanılmamıştır. En fazla tercih edilen göz izleyici Tobii X2-60 olmuştur. Matematik eğitiminde göz izleme teknolojisi kullanılarak çalışılan konuların başında problem çözme stratejileri ve kullanılabilirlik çalışmaları gelmektedir.

Anahtar Kelimeler: Betimsel araştırma, göz hareketleri, göz izleme, lisansüstü tezler, matematik eğitimi

Geniş Özet

Giriş

Teknolojinin gelişmesi teknolojik yenilikleri insanlığın hizmetine sunmanın yanı sıra farklı disiplinlerde yeni bilimsel yöntemlerin gelişmesine de imkân tanımıştır. Bu yöntemlerden birisi de *göz izleme* (eye tracking) teknolojisidir. Bu teknoloji sayesinde görev esnasında bireyin göz hareketlerini incelemek mümkün hale gelmektedir. Göz izleme teknolojileri sayesinde bireylerin algıları, dikkatleri, hafızaları veya akıl yürütmelerinin altında yatan süreçler hakkında bilgi elde edilmektedir (Maurage vd., 2021). Dolayısıyla, göz hareketlerinin incelenmesi bilişsel sürece ilişkin değerli bilgiler vermektedir (Just & Carpenter, 1976).

Göz izleme teknolojilerinin gelişerek pratikleşmesi ile bu teknoloji birçok disiplinde yaygın olarak kullanılmaya başlanmıştır. Bu disiplinlerden birisi de eğitimdir. Eğitim araştırmaları arasında matematiğin yeri benzersizdir. Matematiğin sembolik ve görsel-uzamsal yapısından dolayı göz izleme yönteminin kullanılması için elverişli bir alandır. Dolayısıyla yıllar içerisinde göz izleme

yöntemi, matematik eğitiminde giderek daha popüler hale gelen bir yöntem olmuştur (Strohmaier vd., 2020). Matematik eğitiminde göz izleme yöntemi matematik temsiller (metin, formül, grafik), matematiksel ve geometrik ispat, dört işlem, işlemsel düşünme, problem çözme süreci ve strateji belirleme, akıl yürütme gibi birçok alanda kullanılmaktadır (Andrà vd., 2009; Alqassab vd., 2018; Chesney vd., 2013; Curtis vd., 2016; De Corte, & Verschaffel, 1986; Ischebeck vd., 2016; Okamoto, & Kuroda, 2014; Plummer vd., 2017).

Uluslararası literatürde matematik eğitiminde göz izleme yöntemi kullanılarak yürütülmüş çalışmaların incelendiği birçok araştırma mevcuttur (Mock vd., 2016; Perttula, 2017; Lilienthal & Schindler, 2019; Strohmaier vd., 2020). Matematik eğitimi çalışmalarında göz izleme teknolojilerinin kullanılması uluslararası literatürde yaygın bir çalışma alanı olmasına karşın Türkiye'de henüz emekleme aşamasındadır. Bu sebeple, Türkiye'de yürütülmüş çalışmaların sistematik olarak incelenmesi güncel eğilimlerin belirlenmesine fırsat tanıyacaktır. Literatürde bu kapsamda yürütülmüş bir çalışma bulunmamaktadır. Bu nedenle mevcut çalışma Türkiye'de matematik eğitiminde göz izleme teknolojisi kullanılarak yapılan lisansüstü tezlerin sistematik incelemesini sunarak mevcut eğilimi ortaya çıkarmayı ve literatürdeki boşluğu doldurmayı hedeflemiştir.

Yöntem

Türkiye'de matematik eğitimi alanında göz izleme teknolojisi kullanılarak hazırlanmış tezlerin olabildiğince tam ve dikkatli bir şekilde incelenmesini amaçlayan bu araştırma nitel araştırma yöntemlerinden doküman inceleme desenine göre tasarlanmıştır. Doküman incelemesi, araştırılması hedeflenen olgu veya olgular hakkında bilgi içeren yazılı materyallerin analizini kapsamaktadır (Yıldırım & Şimşek, 2016). Çalışmanın amacı doğrultusunda incelenen dokümanlar, Türkiye'de matematik eğitimi alanında göz izleme teknolojisi kullanılarak yapılmış yüksek lisans ve doktora tezlerini kapsamaktadır.

Çalışmanın örneklemi Türkiye'de matematik eğitimi ile ilgili göz izleme teknolojisi kullanılarak yürütülmüş tezlerden oluşmaktadır. Bu tezlere ulaşabilmek için veri tabanı olarak YÖK'ün Ulusal Tez Merkezi tercih edilmiştir. İnceleme için seçilen tezlerin analizinde içerik analizi yöntemi kullanılmıştır. İçerik analizi, bir mesajın belirli özelliklerinin objektif ve sistematik bir şekilde tanınmasına yönelik çıkarımların yapıldığı bir tekniktir (Büyüköztürk vd., 2017).

Bulgular ve Tartışma

Türkiye'de göz izleme teknolojisi kullanılarak yürütülmüş matematik eğitimi ile ilgili toplam 12 lisansüstü tez bulunmaktadır. Bu çalışmaların ilki 2010 yılına aittir (Tonbuloğlu, 2010). Matematik eğitimi ile ilgili tezlerde göz izleme teknolojisinin kullanımı, 2019 yılı itibari ile popülerlik kazanarak daha fazla araştırmacının ilgisini çekmiştir. Ülkemizdeki tezlerin yayınlanma eğilimi ile uluslararası literatürdeki yayın eğilimi paralellik göstermektedir.

Türkiye'de ilgili konuda en fazla doktora tezine ev sahipliği yapan kurum Hacettepe Üniversitesi olmuştur. En fazla yüksek lisans tezine ev sahipliği yapan kurum ise Orta Doğu Teknik Üniversitesi

olmuştur. Yürütülen tez çalışmalarının büyük çoğunluğu bilgisayar ve öğretim teknolojileri eğitimi bilim dalı ve bilişim sistemleri bilim dalında üretilmiştir. Matematik eğitimi bilim dalında ise yalnızca bir adet tez üretildiği görülmektedir. Göz izleme araştırmalarının sağlıklı bir şekilde yürütülebilmesi için teknoloji bilgisi gereklidir ancak yeterli değildir. Matematiksel etkinlikler sırasında göz izleme çalışmalarının yürütülmesi diğer alanlarda başarılı şekilde uygulananlardan farklı veya değiştirilmiş yaklaşımlar gerektirebilir (Strohmaier vd., 2020). Bu sebeple, yürütülen matematik eğitimi çalışmalarına alan uzmanlarının dahil olması önemlidir. Bu sayede alanın gerektirdiklerine uygun olarak araştırma yöntemi tasarlanabilir ve elde edilen veriler daha anlamlı şekilde yorumlanabilir.

Türkiye'de matematik eğitimi ile ilgili yürütülmüş göz izleme tezlerinde çoğunlukla lisans ve lisansüstü öğrenciler ile çalışılmıştır. Bu durum uluslararası literatürle benzerlik göstermektedir (Alemdağ & Çağıltay, 2018; Hahn & Klein, 2022; Strohmaier vd., 2020). Göz izleme çalışmalarının deneysel bir süreci içermesi ve laboratuvar ortamına ihtiyaç duyulması sebebiyle üniversitelere sabit bir laboratuvar ortamı kurularak göz izleme çalışmaları bu laboratuvarlarda gerçekleştirilmektedir. Bu nedenle genel olarak üniversite öğrencileri ile çalışma tercih edildiği düşünülmektedir.

Göz izleme araştırmaları deneysel bir süreç gerektirmesi ve çok fazla veri sağlaması sebebiyle genel olarak az sayıda katılımcı ile gerçekleştirilmektedir (Chen & Yang, 2014). Türkiye'de matematik eğitimi ile ilgili yürütülmüş tezler 8 (Malcı, 2021; Türkoğlu, 2014) ila 115 (Armut, 2021) arasında katılımcı ile gerçekleştirilmiştir. Ortalama katılımcı sayısı ise 42,4'tür. Yüksek lisans çalışmaları genel olarak 30'dan az öğrenci ile gerçekleştirilirken doktora çalışmaları 30'dan fazla öğrenci ile gerçekleştirilmiştir.

Göz izleme verilerini bir bağlam içerisinde yorumlamak zor olduğundan dolayı araştırmaların ipuculu geriye dönük sesli düşünme protokolü ile desteklenmesi önerilmektedir (Elling vd., 2011; Tobii Technology, 2009). Yapılan incelemede Türkiye'de matematik eğitimi ile ilgili yürütülen göz izleme tezlerinde genel olarak herhangi bir görüşmenin kullanılmadığı belirlenmiştir. Görüşme yapılan tezlerde ise eş zamanlı sesli düşünme, yarı yapılandırılmış görüşme ve yapılandırılmış görüşme yöntemleri kullanılmıştır. Tezlerde geriye dönük sesli düşünme yönteminin hiç kullanılmaması dikkat çekicidir. Bu durumun geriye dönük sesli düşünme yönteminin diğer yöntemlere kıyasla daha fazla zaman gerektirmesinden kaynaklandığı düşünülmektedir.

Matematik eğitiminde yürütülen göz izleme tezlerinde kullanılan cihazların neredeyse tamamı statik olmakla birlikte yalnızca bir tanesi mobil (gözlük) formdadır. Araştırmalarda çoğunlukla Tobii marka göz izleme cihazları kullanılmıştır. En çok tercih edilen göz izleme cihazı modeli 60 Hz'lik veri örnekleme frekansı sağlayan Tobii X2-60'tır.

Türkiye'de göz izleme teknolojisi kullanılarak yapılan matematik eğitimi tezlerinde genel olarak problem çözme stratejileri, grafikli soru okuma becerisi, kullanılabilirlik, zihinsel döndürme süreci, soru türlerine ve sunum biçimlerine göre yanıtların incelenmesi, test ve madde istatistiklerinin incelenmesi, çoklu temsil kullanımının incelenmesi ve öğretimin etkililiğinin değerlendirilmesi konularında çalışma yapıldığı belirlenmiştir.

Introduction

With the development and introduction of technology into our lives, the 21st century has begun to be called the "information age" or "digital age". This age has not only brought technological innovations to the service of humanity, but also enabled the development of new scientific methods in different disciplines. One of these methods is eye-tracking technology.

Visual information first reaches the eye. For this reason, the eyes are an important source for analyzing information. Various eye-tracking methods and technologies have been introduced over the years to analyze eye movements. Eye-tracking technologies have a history of about 150 years. Javal's (1878) study is considered to be the first source in which eye movements were analyzed. In this study, the researcher used a method involving physical contact. In his later studies, he observed eye movements with the help of mirrors (Javal, 1879). These methods, which were based on observation in the early years, were harmful and impractical. However, with the continuation of research and the development of technology, the methods were tried to be improved and their disadvantages were tried to be eliminated. Thus, the eye-tracking method has become more useful and practical.

Eye-tracking technologies provide information about the processes underlying individuals' perception, attention, memory, or reasoning (Maurage et al., 2021). Therefore, the study of eye movements provides valuable information about the cognitive process (Just & Carpenter, 1976). The devices used for eye tracking are of two types: static systems and mobile systems. Static systems are typically connected to stimuli presented on a computer screen. In contrast, mobile systems are devices worn on an individual's head or integrated into eyeglasses (Hahn & Klein, 2022; Holmqvist et al., 2011).

Eye-tracking data is difficult to assess and interpret on its own as it does not provide context for the researcher. Therefore, eye-tracking data should be combined with other methods and data that provide additional information about participants' experiences (Tobii Technology, 2009). The primary method that provides data about participants' experiences is interviews. Eye-tracking studies are generally supported by a think-aloud protocol (Alhadreti et al., 2017; Olmsted-Hawala et al., 2010). The think-aloud protocol is divided into two retrospective and concurrent. In the synchronous think-aloud method, the participant makes verbal explanations about the task while completing the task (Hyrskykari et al., 2008). When the participant expresses himself/herself while completing the task, his/her attention is divided and may lead to misleading results. In the retrospective think-aloud method, after completing the task, the participant makes a verbal explanation about how the task was completed (Hyrskykari et al., 2008). However, since recall problems may also occur in this method, fabricated or incomplete expressions may be used (Elling et al., 2011). In order to avoid these disadvantages, the cued retrospective think-aloud method is recommended (Elling et al., 2011; Tobii Technology, 2009). In this method, participants are given cues (such as video, gaze graph or gaze video) that help them remember the process after the task is completed and asked to think aloud retrospectively (Van Gog et al., 2005).

With the development and practicalization of eye-tracking technologies, this technology has been widely used in many disciplines. One of these disciplines is education. Mathematics has a unique place

among educational research. Due to the symbolic and visual-spatial structure of mathematics, it is a favorable field for the use of eye-tracking method. Therefore, over the years, eye tracking has become an increasingly popular method in mathematics education (Strohmaier et al., 2020). In mathematics education, the eye-tracking method is used in many areas such as mathematical representations (text, formula, graph), mathematical and geometric proof, four operations, procedural thinking, problem solving process and strategy determination, reasoning (Andrà et al., 2009; Alqassab et al., 2018; Chesney et al., 2013; Curtis et al., 2016; De Corte, & Verschaffel, 1986; Ischebeck et al., 2016; Okamoto, & Kuroda, 2014; Plummer et al., 2017).

In the international literature, there are many studies examining studies using eye-tracking methods in mathematics education. Mock et al. (2016) conducted a study on numerical cognition to evaluate the added value of eye tracking in investigating number processing. Perttula (2017) conducted a study on mathematical representations. Lilienthal and Schindler (2019) examined mathematics education studies published in the PME (Psychology of Mathematics Education) symposium in terms of the eye trackers and types of analysis used. As a result of all these studies, Strohmaier et al. (2020) conducted a systematic review on mathematics education. In this study, 161 eye-tracking studies were examined and these studies were analyzed in the categories of publication year, journal, topic, eye tracker type, stimuli (task type, presentation, interest area), sample, research design, data processing, and interpretation of eye movements.

Although the use of eye-tracking technologies in mathematics education studies is a common field of study in the international literature, it is still in its infancy in Türkiye. Therefore, a systematic review of studies conducted in Türkiye will provide an opportunity to identify current trends. There is no study conducted in this context in the literature. Therefore, the research problem of the current study was determined as 'What is the current trend of graduate theses conducted using eye-tracking technology in mathematics education in Türkiye?'.

Purpose of the study

The field of mathematics education is unique among educational research fields in the way it uses text, mathematical symbols and visualizations and how these forms of representation are integrated (Andrà et al., 2009; Ott et al., 2018). The study conducted by Strohmaier et al. (2020) shows that the number of studies using eye tracking in mathematics education has increased rapidly in the last decade, with approximately 20 studies published annually. Using the eye-tracking method in the field of mathematics education provides various advantages to the researcher. Strohmaier et al. (2020) list them under three items:

1. What is considered important in mathematics education is not the answer to a problem, but the strategies used and the paths followed by students in solving that problem. Eye-tracking practices are practices that focus on the process rather than the result. Therefore, using the eye-tracking method in mathematics education studies provides the opportunity to observe solution processes without disturbing students (e.g., Inglis & Alcock, 2012; Obersteiner & Tumpek, 2016).

2. Mathematics makes use of visualizations in many forms such as graphs, tables, etc. At the same time, mathematical objects are generally abstract in nature. Therefore, visualization and mental representations are important issues for mathematics education. It is quite difficult to identify the mental representations in students' minds. Eye tracking is a method that helps to make mental representations of mathematical objects visible (e.g., Hartmann et al., 2016; Myachykov et al., 2015).
3. Cognitive processes in mathematical thinking are often complex. Therefore, it is very difficult to understand the cognitive process of students, especially in younger age groups. The eye-tracking method sheds light on cognitive processes that cannot be consciously reported (e.g., Moeller et al., 2009; Ott et al., 2018).

Considering the increasing prevalence of eye tracking in mathematics education and the advantages of this method in mathematics education, it was deemed important to determine the profile of eye-tracking studies in the field of mathematics education in Türkiye. In this context, the present article aims to fill the gap in the literature by presenting a systematic review of graduate studies in the field of mathematics education in Türkiye using the eye-tracking technology. In order to determine the current trend, the types, years, universities, disciplines, number of participants, research methods used, types of interviews used, eye-tracking models and topics studied were examined.

The findings of this study can be an important reference for researchers in terms of revealing the current trends in the field in terms of descriptive, methodology, and topic information. In addition, analyzing and revealing the general outlook of graduate studies conducted using eye-tracking technology in the field of mathematics education is important in terms of contributing to the development of the field and the researchers who will work in the field. In addition, comparing the findings of the study with international systematic studies will contribute to identifying gaps in Türkiye or areas where there is room for improvement. In this framework, the findings of the study are important in terms of contributing to the researchers to examine more current issues with different methods, participant groups and analysis techniques by examining the status of the studies conducted in the field.

Method

Research design

This study, which aims to examine the theses prepared using eye-tracking technology in the field of mathematics education in Türkiye as completely and carefully as possible, was designed according to the document review design, one of the qualitative research methods. Document review involves the analysis of written materials containing information about the phenomenon or phenomena targeted for research (Yıldırım & Şimşek, 2016).The documents examined for the purpose of the study include master's and doctoral theses in the field of mathematics education in Türkiye using

eye-tracking technology. The current study is not subject to ethics committee approval as no human data was collected.

Data collection procedures

The sample of the study consists of theses on mathematics education in Türkiye that were conducted using eye-tracking technology. In order to access these theses, CoHE Theses Center was preferred as a database. The keywords " göz izleme", " göz hareketi", " göz takip", "eye movement", "eye tracking" and "eye-tracking" were used to search the database (Access Date: 04.08.2023). The subject area was limited to the categories of "education and training" and "mathematics". Since it was aimed to examine all theses published in the national literature, no year limitation was made. All thesis studies published until August 2023 were included in the study. Information about the data collection process that took place as a result of the aforementioned restrictions is given in Figure 1.

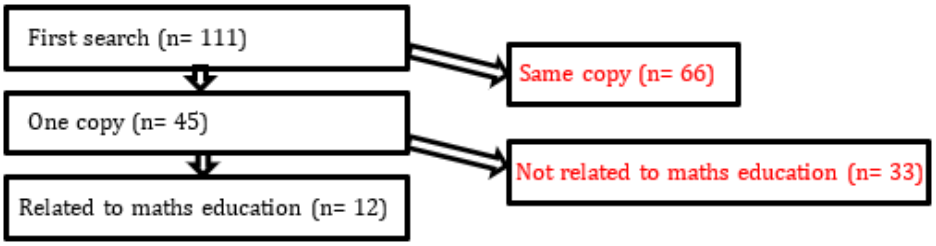


Figure 1. Data collection processes.

As a result of the search in the database, 111 theses were reached. While 107 of them are in the subject area of education and training, 4 of them are in the subject area of mathematics. Among the theses, 66 repeated theses were excluded from the analysis. This left a total of 45 theses, 43 in the field of education and training and 2 in the field of mathematics. Finally, when the abstracts and methods of these theses were examined in detail, theses that were not related to mathematics education were eliminated. At the end of the theses selection process, 12 follow-up studies that were found to be related to mathematics education were identified for the current review (Akal, 2019; Armut, 2021; Bağçıvan, 2022; Bayazıt, 2013; Coşguner, 2022; Karaca, 2023; Malcı, 2021; Tonbuloğlu, 2010; Türkoğlu, 2014; Uzunosmanoğlu, 2013; Yağmur, 2014; Yılmaz, 2019).

In the examination of the theses, the graduate theses examination form created by the researchers in accordance with the objectives of the study was used as a data collection tool. The graduate theses review form was created by the researchers before the examination of the theses by looking at the theses review forms previously used in the relevant literature (Göktaş et al., 2012; Uçar & Akbolat, 2021; Yardim & Engin, 2021). In the form, descriptive characteristics (type, publication year, university, department), methodological information (research method, participation audience, sample size, interview technique, type of eye tracker) and topic information were included.

Data analysis

Content analysis method was used to analyze the theses selected for the analysis. Content analysis is a technique in which inferences are made to recognize certain features of a message in an objective and systematic way (Büyüköztürk et al., 2017). According to this method, the data obtained are summarized and interpreted according to predetermined themes (Yıldırım & Şimşek, 2016).

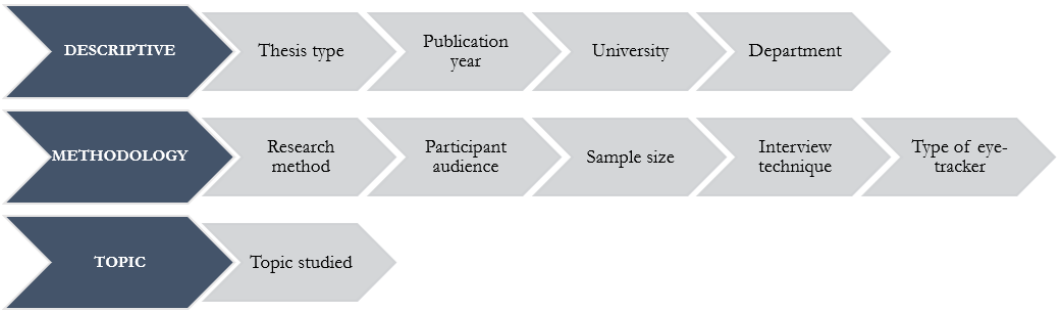


Figure 2. Data analysis categories.

The theses selected for analysis were analyzed under three headings: descriptive, methodology, and topic information (Figure 2). Descriptive characteristics include the type of theses, year, university, and discipline in which the theses were published. Methodology information includes information such as the research method, participant population, sample size, type of interview and type of eye tracker used. Finally, under the heading of topic information, there is information on the specific topic of the research. The findings are presented in tables as frequency (f) and percentage (%).

Findings

The present study, it is aimed to reveal the current trend in graduate theses conducted in the field of mathematics education in Türkiye using eye-tracking technology. The findings obtained for this purpose are presented under the headings of descriptive, methodology and topic information respectively.

Descriptive findings

In CoHE Theses Center, 12 studies on mathematics education in which eye-tracking technology was used were found. Statistical information about the type of theses is given in Table 1.

Table 1. Distribution of Graduate Theses according to Type.

Theses Type	f	%
Master Theses	7	58,3
Doctoral Theses	5	41,7

When the Table 1 is examined, it is seen that the majority of these studies were produced in the master's degree type. It was determined that there were 7 (58,3%) master's theses and 5 (41,7%) doctoral theses conducted using eye-tracking technology in the field of mathematics education in Türkiye. Statistical information on the years in which graduate theses were published is given in Table 2.

Table 2. Distribution of Graduate Theses according to Publication Year.

Year	Master Theses		Doctoral Theses		Total	
	f	%	f	%	f	%
2010	1	14,3	0	0,0	1	8,3
2013	1	14,3	1	20,0	2	16,7
2014	2	28,5	0	0,0	2	16,7
2019	1	14,3	1	20,0	2	16,7
2021	1	14,3	1	20,0	2	16,7
2022	1	14,3	1	20,0	2	16,7
2023	0	0,0	1	20,0	1	8,3
Total	7	100,0	5	100,0	12	100,0

When the Table 2 is examined, it is seen that the use of eye-tracking technology in mathematics education theses in Türkiye started with a master's study in 2010. Doctoral dissertations started to be published in 2013. When the table is analyzed, it is seen that the publication process that started in 2010 continued in 2013 and 2014.. However, no publications were produced for four years between 2014 and 2019. Then, as of 2019, the field of study came to the agenda again and more regular publications started to be produced. The historical development of theses in the field of mathematics education in Türkiye using eye-tracking technology is given in Figure 3.

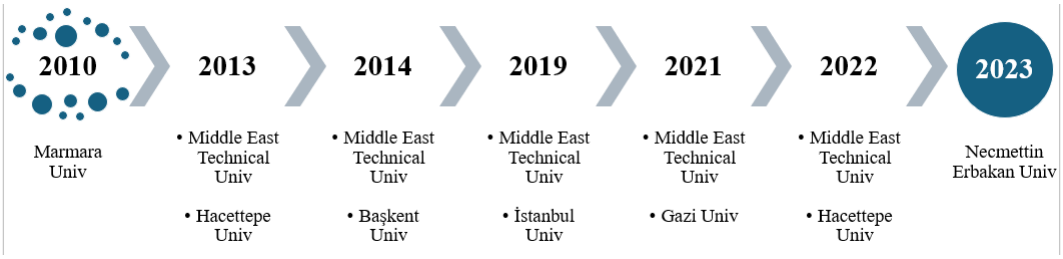


Figure 3. Universities publishing by years.

According to Figure 3, it is seen that the first thesis study on the related subject was conducted at Marmara University in 2010. Afterwards, it is noteworthy that Marmara University has not produced any thesis on the related subject. Middle East Technical University, on the other hand, started to produce theses in 2013 and produced regular publications in the following years. Detailed statistical information about the universities producing publications on the related subject is given in Table 3.

Table 3. Distribution of Graduate Theses according to Universities.

University	Master Theses		Doctoral Theses		Total	
	f	%	f	%	f	%
Başkent University	1	14,3	0	0,0	1	8,3
Gazi University	0	0,0	1	20,0	1	8,3
Hacettepe University	0	0,0	2	40,0	2	16,7
İstanbul University	1	14,3	0	0,0	1	8,3
Marmara University	1	14,3	0	0,0	1	8,3
Necmettin Erbakan University	0	0,0	1	20,0	1	8,3
Orta Doğu Teknik University	4	57,1	1	20,0	5	41,7

When the table is examined, it is seen that although master's theses were conducted in 4 different universities, the majority of the theses were conducted at Middle East Technical University (METU) (f=4, 57,1%). Doctoral theses were conducted in 4 different universities and the university with the highest number of publications was Hacettepe University (f=2, 40,0%). When the graduate theses are evaluated together, it is seen that 7 different universities published on the related topic. Middle East Technical University (METU) (f= 5, 41,7%) produced the highest number of theses among the universities. Statistical information about the disciplines in which the theses in which eye-tracking technology was used in the field of mathematics education were conducted is given in Table 4.

Table 4. Distribution of Graduate Theses according to Disciplines.

Disciplines	Master Theses		Doctoral Theses		Total	
	f	%	f	%	f	%
Computer Education and Instructional Technology (CEIT)	4	57,1	1	20,0	5	41,7
Information Systems	2	28,6	0	0,0	2	16,7
Mathematics Education	0	0,0	1	20,0	1	8,3
Assessment and Evaluation in Education	0	0,0	1	20,0	1	8,3
Educational Technology	1	14,3	0	0,0	1	8,3
Preschool Education	0	0,0	1	20,0	1	8,3
Teaching Turkish as a Foreign Language	0	0,0	1	20,0	1	8,3

When the table is examined, it is seen that the majority of the theses were conducted in the Department of Computer Education and Instructional Technology (f=5; 41,7%) and the Department of Information Systems (f=2; 16,7%). In addition to these, theses studies were also conducted in Mathematics Education, Assessment and Evaluation in Education, Educational Technology, Preschool Education and Teaching Turkish as a Foreign Language.

Methodology Findings

When the eye-tracking theses conducted in the field of mathematics education are examined, it is seen that the theses are generally designed in accordance with mixed (f=6; 50,0%) and quantitative (f=4; 33,4%) research methods. Detailed statistical information on the research methods used in the theses studies is given in Table 5.

Table 5. Distribution of Graduate Theses according to Research Methods.

Research Methods		Master Theses		Doctoral Theses		Total	
		f	%	f	%	f	%
Quantitative	Correlational	0	0,0	2	40,0	2	16,7
	Experimental	1	14,3	1	200	2	16,7
Qualitative	Case study	1	14,3	0	0,0	1	8,3
Mixed		5	71,4	1	20,0	6	50,0
Not stated		0	0,0	1	20,0	1	8,3
Total		7	100,0	5	100,0	12	100,0

When Table 5 is examined, it is seen that the majority of master's theses were designed according to mixed research method (f=5; 71.4%), while doctoral theses were designed according to quantitative research method (f=3; 60.0%). Among quantitative research methods, correlational (f=2; 40,0%) and experimental (f=1; 20,0%) research methods were preferred. Table 6 presents statistical information about the participant groups in which the eye-tracking theses in mathematics education in Türkiye were conducted. Since some studies were conducted with more than one participant group at the same time, the frequency sum in the table differs from the number of theses.

Table 6. Distribution of Graduate Theses according to Participant Audience.

Participant Audience	Master Theses		Doctoral Theses		Total	
	f	%	f	%	f	%
Preschool student	0	0,0	1	16,7	1	6,3
Primary school student	1	10,0	1	16,7	2	12,5
Secondary school student	1	10,0	1	16,7	2	12,5
Undergraduate student	5	50,0	1	16,7	6	37,5
Graduate student	3	30,0	1	16,7	4	25,0
TÖMER/DİLMER student	0	0,0	1	16,7	1	6,3

When Table 6 is examined, it is seen that the master's studies were mostly conducted with undergraduate (f=5; 50,0%) and graduate (f=3; 30,0%) students. In addition, master's studies were also conducted with primary (f=1; 10,0%) and secondary (f=1; 10,0%) students. Doctoral studies were conducted with undergraduate (f=1; 16,7%), graduate (f=1; 16,7%), preschool (f=1; 16,7%), primary (f=1; 16,7%), secondary (f=1; 16,7%) and TÖMER/DİLMER (f=1; 16,7%) students. When the graduate theses are evaluated together, it is seen that the highest number of participants were undergraduate (f=6; 37,5%), graduate (f=4; 25,0%), primary (f=2; 12,5%) and secondary (f=2; 12,5%) students, respectively. Statistical information on the number of participants in the conducted theses is given in Table 7. Sample numbers were classified according to the reference intervals in the classification form of Göktaş et al. (2012). The theses in the related literature were conducted with an average of 42,5 participants ranging from N_{min}= 8 (Malcı, 2021; Türkoğlu, 2014) to N_{max}= 115 (Armut, 2021).

Table 7. Distribution of Graduate Theses according to Sample Size.

Sample Size	Master Theses		Doctoral Theses		Total	
	f	%	f	%	f	%
1-10	3	42,9	0	0,0	3	25,0
11-30	3	42,9	0	0,0	3	25,0
31-50	0	0,0	1	20,0	1	8,3
51-70	1	14,3	3	60,0	4	33,3
71-100	0	0,0	0	0,0	0	0,0
101+	0	0,0	1	20,0	1	8,3
Total	7	100,0	5	100,0	12	100,0

When Table 7 is examined, it is seen that master's studies are generally conducted with less than 30 students, while doctoral studies are conducted with more than 30 students. When the postgraduate studies were evaluated together, the highest number of students was 51-70 (f=4; 33,3%). The number of participants followed by 1-10 (f=3; 25,0%) and 11-30 (f=3; 25,0%).

When the eye-tracking theses conducted in the field of mathematics education are examined, it is seen that interviews were not conducted in most of the theses. Detailed statistical information according to theses types is given in Table 8. Since more than one type of interview can be used in a theses, the total frequency is different from the number of theses.

Table 8. Types of Interviews Used in Graduate Theses.

Interviews Types	Master Theses		Doctoral Theses		Total	
	f	%	f	%	f	%
Concurrent think aloud	2	25,0	0	0,0	2	15,4
Semi-structured interview	2	25,0	0	0,0	2	15,4
Structured interview	2	25,0	0	0,0	2	15,4
No interview	2	25,0	5	100,0	7	53,8

When Table 8 is examined, it was determined that interviews were not used in all doctoral theses. In master's theses, it was determined that interviews were generally used. The interview types used were concurrent think aloud (f=2; 25,0%), semi-structured interview (f=2; 25,0%) and structured interview (f=2; 25,0%).

One of the most important elements of eye-tracking studies is the eye trackers used. Since each device has different features, sensitivity and accuracy levels, it is important to know the eye trackers used in the studies. It is seen that many different devices were used in theses conducted in the field of mathematics education in Türkiye using eye-tracking technology. Statistical information about the devices used is given in Table 9.

Table 9. Eye Tracker Models Used in Graduate Theses.

Eye Tracker		Master Theses		Doctoral Theses		Total	
		f	%	f	%	f	%
Tobii	X2-60	3	33,3	1	20,0	4	28,6
	T-70	0	0,0	1	20,0	1	7,1
	T-120	2	22,2	0	0,0	2	14,3
	T-1750	1	11,1	0	0,0	1	7,1
	TX-300	0	0,0	1	20,0	1	7,1
	Pro Glasses 2	0	0,0	1	20,0	1	7,1
	Model unspecified	1	11,1	0	0,0	1	7,1
Gaze Point GP3		0	0,0	1	20,0	1	7,1
SMI Experiment		2	22,2	0	0,0	2	14,3

When the table is examined, it is seen that Tobii brand devices are generally preferred. Although the majority of the devices used in the theses were screen-based (static) devices, only one theses used a device in the form of glasses (mobile) (Tobii Pro Glasses 2). The most preferred models were Tobii X2-60 (f=4; 28,6%), Tobii T-120 (f=2; 14,3%) and Senso Motoric Instruments (SMI) Experiment (f=2; 14,3%).

Topic Information Findings

Eye-tracking technology has been used in many different subjects in the field of mathematics education in the international literature. In order to determine the specific topics of the eye-tracking theses in the field of mathematics education in Türkiye, the topics of the related theses were examined. Statistical information about the topics covered in the theses is given in Table 10.

Table 10. Topic Distribution of Graduate Theses.

Topic	Master Theses		Doctoral Theses		Total	
	f	%	f	%	f	%
Problem solving strategies	3	42,9	0	0,0	3	25,0
Ability to read questions with graphs	0	0,0	1	20,0	1	8,3
Usability	3	42,9	0	0,0	3	25,0
Mental rotation process	1	14,3	0	0,0	1	8,3
Analyzing responses according to question types and presentation styles	0	0,0	1	20,0	1	8,3
Examination of test and item statistics	0	0,0	1	20,0	1	8,3
Examining the use of multiple representation	0	0,0	1	20,0	1	8,3
Effectiveness of teaching	0	0,0	1	20,0	1	8,3
Total	7	100,0	5	100,0	12	100,0

When the table is analyzed, it is seen that the majority of the studies are examining problem solving strategies (f=3; 25,0%) and usability (f=3; 25,0%). In addition to these, theses studies were also carried out on the ability to read questions with graphics, mental rotation process, examination

of answers according to question types and presentation styles, test and item statistics, use of multiple representation and effectiveness of teaching.

Discussion, Conclusion, and Suggestions

In Türkiye, there are a total of 12 graduate theses on mathematics education using eye-tracking technology. The first of these studies is from 2010 (Tonbuloğlu, 2010). The use of eye-tracking technology in theses on mathematics education has gained popularity as of 2019 and attracted the attention of more researchers. The publication trend of the theses in our country and the publication trend in the international literature are parallel. In the international literature, the use of eye-tracking technology has gained popularity since 2008 (Carter & Luke, 2020). Eye-tracking studies on learning have become popular since 2009 (Lai et al., 2013). Strohmaier et al. (2020) found a significant increase in studies on mathematics education between 2006 and 2014. According to this study, the number of eye-tracking studies on mathematics education in the international literature has started to increase since 2006. The related subject area has become popular since 2014. Lilienthal and Schindler (2019) also reported at the PME symposium that eye-tracking studies in mathematics education started to be conducted as of 2013. In line with the findings obtained from the current study, it is seen that the national literature closely follows the international literature.

When the universities hosting the theses are evaluated, the highest number of doctoral theses were conducted at Hacettepe University (Bayazıt, 2013; Coşguner, 2022). However, no master's studies were conducted at this university. Similarly, while most master's theses were conducted at Middle East Technical University (Bağçıvan, 2022; Malcı, 2021; Uzunosmanoğlu, 2013; Yağmur, 2014), only one doctoral theses was produced at this university (Yılmaz, 2019). This shows us that universities focus on certain theses types and gain expertise in those theses types. When all theses types are evaluated together, it is seen that Middle East Technical University is the university that conducts the most theses using eye-tracking technology in the field of mathematics education. The university's first theses on the related topic was produced in 2013. It is thought that the fact that METU has its own Human-Computer Interaction Research and Application Laboratory plays a role in this situation. This laboratory was established in 2006, but as of 2012, in accordance with the "ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories" standard of the Turkish Standards Institute (TSE), it was authorized as the first and only accredited laboratory of TSE in Türkiye, where product certification studies will be carried out within the scope of "TS EN ISO/IEC 9241-151 Ergonomics of Human-System Interaction – Part 151: Guidance on World Wide Web User Interfaces" (Middle East Technical University, n. d.). For this reason, it is estimated that the university has gained momentum in publication production as of 2013. In addition to METU, there are human-computer interaction laboratories at Gebze Technical University, Istanbul University, Hacettepe University, Boğaziçi University, Eskişehir Technical University, Anadolu University and Eskişehir Osmangazi University.

Master's theses studies aim for students to gain basic research skills such as research, use of academic language, data analysis and presentation of data. Doctoral theses studies, on the other

hand, require more expertise, time, and in-depth study in the field. In our country, mathematics education studies conducted using eye-tracking technology are generally at the master's level. The insufficiency of doctoral theses in the field shows that more studies should be conducted in this field.

The majority of the theses studies conducted in Türkiye were produced in computer education and instructional technology discipline (Akal, 2019; Bağçıvan, 2022; Bayazıt, 2013; Malcı, 2021; Tonbuloğlu, 2010; Türkoğlu, 2014) and information systems discipline (Uzunosmanoğlu, 2013; Yağmur, 2014). Only one theses was produced in the field of mathematics education (Karaca, 2023). Technology knowledge is necessary but not sufficient for eye-tracking studies to be conducted in a healthy way. Conducting eye-tracking studies during mathematical activities may require different or modified approaches from those successfully applied in other fields (Strohmaier et al., 2020). For this reason, it is important to involve field experts in mathematics education studies. In this way, the research method can be designed in accordance with the requirements of the field and the data obtained can be interpreted more meaningfully. Therefore, in-depth investigations can be conducted with the involvement of field experts in the research process.

Most of the eye-tracking theses on mathematics education in Türkiye were conducted with undergraduate and graduate students. This is similar to the international literature (Alemdağ & Çağıltay, 2018; Hahn & Klein, 2022; Strohmaier et al., 2020). Strohmaier et al. (2020) consider the predominance of university students in eye-tracking studies in mathematics education to be problematic since many topics in mathematics education are related to school-age children. However, due to the nature of the eye-tracking application, the researcher was provided with a variety of materials such as eye trackers, control computers, monitors, voice recorders, etc. in eye-tracking applications. In addition, since eye-tracking studies basically aim to measure attention, it should be applied in an environment free from distracting factors. Therefore, a laboratory environment is needed. Since it is a laborious process to invite students to the laboratory or to move the laboratory to the schools where the implementation will take place, a fixed laboratory environment is usually created in universities. Therefore, working with students studying in institutions where the laboratory is available facilitates the implementation process. In addition, in eye-tracking studies, participants are expected to pay attention to the relevant stimulus for a certain period of time. Considering the developmental characteristics of young students, it is very difficult for them to pay attention to a stimulus for a long time. For all these reasons, it is thought that university students are preferred in eye-tracking studies.

Eye-tracking studies are generally conducted with a small number of participants because they require an experimental process and provide a lot of data (Chen & Yang, 2014). In Türkiye, theses on mathematics education were conducted with between 8 (Malcı, 2021; Türkoğlu, 2014) and 115 (Armut, 2021) participants. The average number of participants was 42,4. This is in line with the systematic reviews on eye tracking in the literature. Hahn and Klein (2022) conducted a systematic review in the field of physics education and found that research was conducted with an average of 54,4 participants ranging from 15 to 119. In Strohmaier et al.'s (2020) review in the field of mathematics education, it was determined that the average number of participants per experiment was 28,56.

Qualitative research methods provide more in-depth information than quantitative methods (Karataş, 2015). Considering that doctoral theses are more specialized studies, it is thought that qualitative methods can be used more in doctoral theses compared to master's theses. However, as a result of the current review, contrary to expectations, it was determined that almost all of the master's theses were designed in accordance with qualitative and mixed research methods (Akal, 2019; Karaca, 2023; Malcı, 2021; Tonbuloğlu, 2010; Türkoğlu, 2014; Uzunosmanoğlu, 2013; Yağmur, 2014). Almost all of the doctoral dissertations were designed in accordance with the quantitative research method (Armut, 2021; Coşguner, 2022; Yılmaz, 2019). Since there is no study examining theses in the international literature, it is not yet possible to compare the methods used in theses with the international literature. For this reason, when the theses analyzed in the current study were evaluated as a whole, it was determined that mixed and quantitative designs were generally used in the studies, respectively. This situation is similar to the international literature. Strohmaier et al. (2020) found that 54% of the studies they examined used within-subject design or mixed design. Lilienthal and Schindler (2019) also reported that the majority of the papers published in PME were designed according to the quantitative method. In line with this information, it was concluded that the national and international literature is similar and that mixed and quantitative methods are generally used in eye-tracking studies in mathematics education.

As a result of the analysis, it was determined that the number of participants differed significantly according to theses types. While master's studies were generally conducted with less than 30 students, doctoral studies were conducted with more than 30 students. The reason for this is that master's theses are designed according to qualitative and mixed research method while doctoral theses are designed according to quantitative research method. In quantitative research, the number of participants should be high in order to make generalizations, while in qualitative research, it is appropriate to work with fewer students in order to make in-depth analysis (Marshall, 1996; Teddlie & Yu, 2007).

Since it is difficult to interpret eye-tracking data in a context, research is generally supported by a think-aloud protocol (Alhadreti et al., 2017; Boren & Ramey, 2000; Elling et al., 2011; Olmsted-Hawala et al., 2010). Among the think-aloud protocols, it is recommended to use the cued retrospective think-aloud method (Elling et al., 2011; Tobii Technology, 2009). In the review, it was determined that in general, no interviews were used in the eye-tracking theses conducted on mathematics education in Türkiye. In the theses where interviews were conducted, concurrent think aloud, semi-structured interview and structured interview methods were used. It is noteworthy that retrospective think aloud method was never used in the theses. This is thought to be due to the fact that retrospective think aloud method requires more time compared to other methods.

Almost all of the devices used in the eye-tracking theses conducted in mathematics education are static and only one of them is mobile (glasses). Mostly Tobii brand eye tracker were used in the studies. The most preferred eye-tracker model is the Tobii X2-60, which provides a data sampling frequency of 60 Hz. Tobii T-120 and SMI Experiment were the next most frequently used devices. This is in line with international literature. As a result of the international literature review, it was determined that static systems are generally used in educational research (Hahn & Klein, 2022;

Lilienthal & Schindler, 2019). Commonly used devices are Tobii, SMI Experiment and SR Research (Belen, 2022; Hahn & Klein, 2022; Strohmaier et al., 2020).

Many topics related to mathematics education can be studied with eye-tracking methods. In their review, Strohmaier et al. (2020) classified the topics studied in the field of mathematics education under the following headings: i) Numbers and arithmetic, ii) Geometry, shape, and form, iii) Reading and word problem solving, iv) Reasoning and proof, v) Use of mathematical representations, vi) Learning difficulties, vii) Computer-supported learning, viii) Mathematical problem solving, ix) Statistics and x) Affective variables. In the current study, it was determined that studies were conducted on problem solving strategies, ability to read questions with graphics, usability, mental rotation process, examination of responses according to question types and presentation formats, examination of test and item statistics, examination of the use of multiple representation and evaluation of the effectiveness of teaching. In addition, it is seen that there is a lack of studies in the subject areas mentioned by Strohmaier et al. (2020) such as numbers and arithmetic, reasoning and proof, learning difficulties, computer-support learning, statistics and affective variables.

In line with the information obtained from the current study, the following suggestions can be made:

It is seen that there is a limited number of theses on eye tracking in the field of mathematics education in Türkiye. The reason for this may be that educators are not familiar with this method and eye-tracking devices are expensive. There are two options for researchers to access eye-tracking devices. The first one is to purchase the device by utilizing certain project supports. The second is to practice in laboratories already established in some universities. For this reason, it is difficult for researchers to conduct new studies on the relevant subject. Therefore, conducting research on the relevant subject and carrying out the process in a healthy way makes collaborative work mandatory.

In order to increase the number of theses on eye tracking in mathematics education in Türkiye, it is important to inform mathematics educators about eye-tracking technology and the types of data it can provide. Encouraging mathematics educators to conduct research on this topic will increase the number of studies on attention in mathematics education. It will also be an opportunity to study more specific topics related to mathematics education such as arithmetic, geometry, statistics, probability, measurement, reasoning and proof, learning difficulties, computer-support learning, and mathematization.

As the existing literature has generally studied undergraduate and graduate students, it is recommended that future research be conducted with participant groups that have been little or never studied before, such as primary school students, secondary school students, and students with special needs. Furthermore, age is an important factor affecting eye movements (Holmqvist et al., 2011; Rayner et al., 2012). Therefore, studying with younger students also means that the generalizability of the findings will increase.

In order for eye-tracking data to be interpreted properly in context, it is recommended that it be used with methods and data that provide additional information about the participants' experiences

(Tobii Technology, 2009). One of these methods is the interview. As a result of the review, it was determined that the interview method is generally not used in the theses conducted in Türkiye and eye-tracking data is used alone. In future studies, it is recommended that the eye-tracking method should be supported with the interview method, especially with the cued retrospective thinking aloud method.

Eye-tracking applications can be carried out with mobile and static-eye trackers. As a result of the current study, it was determined that static eye-trackers were generally used in the theses. Mobile eye-trackers provide the participant with head movement flexibility. Therefore, it is recommended to use mobile eye-trackers in tasks where participants need to observe their surroundings and move physically. In studies conducted on a fixed screen, static eye trackers are recommended.

Ethics Committee Approval: *No procedures requiring ethics committee approval were carried out during the data collection process of this study. Therefore, no Ethics Committee Approval document was obtained.*

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