# *2017-2022 Yılları Arasında Yayınlanan Teknoloji ile Desteklenmiş Matematik Eğitimi Çalışmalarının İçerik Analizi*

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**Öz**

*Bu çalışma, 2017 ve 2022 yılları arasında yayınlanan matematik eğitimi alanında teknoloji ile desteklenmiş öğrenmenin (TEL) gelişen yapısını eleştirel bir şekilde incelemektedir. Web of Science veri tabanında yayınlanan 23 makalenin ayrıntılı içerik analizi yapılarak matematik eğitimi alanındaki güncel teknoloji kullanım trendleri ortaya çıkarılmaya çalışılmıştır. Nitel araştırma yöntemlerinden olan içerik analizinin kullanıldığı çalışmada yayınların coğrafi dağılımı, dergilere göre dağılımı, çalışmalarda ele alınan örneklem, kullanılan teknolojiler ve temel öğrenme teorileri dahil olmak üzere çeşitli değişkenler ele alınmıştır. Çalışmanın temel hedefi, gelecekte yapılacak matematik eğitimi alanındaki çalışmalar için teknoloji kullanımı yönünden araştırmacıları aydınlatabilecek bilgileri ve teknoloji destekli matematik öğretimi süreçlerinde kullanılabilecek teknolojilerle birlikte bu teknolojilerin kullanım şekillerinin süreç içerisinde gösterdiği değişimi ortaya koymaktır. Yapılan içerik analizi sonucunda sonuçlar göstermektedir ki teknoloji destekli matematik eğitiminde kullanılan bazı teknolojilerin farklı öğrenci grupları için matematik eğitimin süreçlerinde daha fazla yer bulmasıyla birlikte teknolojinin benimsenmesindeki dinamik değişimleri vurgulamaktır. Ayrıca yapılan bu inceleme, teknoloji destekli matematik öğretimi çalışmalarına rehberlik eden yaygın öğrenme teorilerine ışık tutmakla birlikte bu akademik teorileri yönlendiren pedagojik temellere işaret etmektedir. Akademisyenlere, öğretim programı geliştiricilere ve eğitimcilere yönelik olan bu çalışma, yalnızca teknoloji ile desteklenmiş matematik eğitimine ışık tutmakla kalmayıp, aynı zamanda gelecekte daha kapsayıcı ve kapsamlı incelemelere olan ihtiyacı vurgulayarak yeni çalışmalarda odaklanılması beklenen konuların ana hatlarını da çizmektedir.*

*Anahtar Kelimeler: Teknoloji destekli öğrenme, Matematik eğitimi, İçerik analizi*

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## GENİŞ ÖZET

### Giriş

Dijital teknolojilerde meydana gelen hızlı gelişim, eğitim alanında yeni bir dönemin kapılarını açtı. Özellikle matematik alanında bu yeni dönem teknolojinin alana entegrasyonu açısından yeni fırsatlar doğurdu. Schweighofer ve Ebner (2015) Teknoloji ile Desteklenmiş Öğrenme (Technology Enhanced Learning/TEL) farklı teknolojik yaklaşımları öğretme ve öğrenmeyi destekleyen kapsamlı bir kavram olarak tanımlamıştır. Lai ve Bower (2020) eğitim teknolojileri araştırmalarında meydana gelen gelişmenin sadece öğrenme çıktılarına odaklanan bir yapıdan çıkarak eğitsel uygulamalara daha geniş bir bakış açısı kazandırdığını ifade etmiştir. Marín ve arkadaşları (2020) ise yüksek öğretim seviyesinde öğrencilerin temsili açısından teknoloji ile geliştirilmiş öğrenmenin yaratıcı ve verimli problem çözme becerileri kazandırılmasında önem taşıdığını ifade etmiştir. Bu içerik analizi çalışması kapsamında teorik çerçeveler teknoloji ile desteklenmiş öğrenme ve matematik eğitimi beraberce ele alınacaktır. İçerik analizi kapsamında kullanılacak çerçeve şekillendirilirken teknoloji ile desteklenmiş öğrenme kavramı Bayne (2014) tarafından bölgesel olarak ifade edilen terimsel gelişimler üzerinden ele alınmıştır.

### Amaç

Bu çalışmanın amacı 2017 ve 2022 yılları arasında Web of Science veri tabanında yayınlanan matematik eğitimi alanında yapılan teknoloji ile desteklenmiş öğrenme çalışmalarının tema ve akımlarının incelenmesidir. Son beş yıllık dönemdeki çalışmaların incelenmesi ile alandaki son gelişmelerin gelecekteki çalışmalara yol göstermesi hedeflenmiştir. Çalışmanın önemi eğitimcilere, öğretim programı geliştiricilere ve akademisyenlere matematik eğitimi alanında teknoloji ile desteklenmiş öğrenme üzerine sunacağı bilgi üzerinde şekillenmektedir.

### Yöntem

Bu çalışma nitel araştırma yöntemlerinden olan içerik analizi yöntemi kullanılarak gerçekleştirilmiştir. Stemler (2001) ve Prasad (2008) tarafından tanımlanan içerik analizi çerçevesinde Web of Science veri tabanında yayınlanmış 23 akademik makale incelenmiştir. Makale seçme süreci özel arama kelimelerinin seçimi ve eleme kriterlerinin oluşturulması başlamış sonrasında matematik, teknoloji ile destekleme ve eğitim temalarına odaklanılmıştır. Prasad (2008) tarafından açıklanan içerik analizi yaklaşımı çerçevesinde gerçekleştirilen analiz sürecinde kodlama ve tema geliştirme basamakları takip edilmiştir.

### Bulgular

Nvivo kullanılarak gerçekleştirilen analiz süreci eğitim alanında yoğunlaşan kavramları merkeze alan on bir tema oluşturulmuştur. Teknoloji ile desteklenmiş öğrenme çerçevesinde yoğunluklu olarak öğrenci memnuniyeti, öğrenci bağlılığı, bilişsel ve duygusal öğrenme alanları ve matematik eğitimine dair yüksek kaliteli dönütlerin varlığı görülmüştür. Oyunlaştırma ve artırılmış gerçeklik gibi teknolojilerin öğrenme motivasyonu ve öğrenme çıktılarına olumlu etkileri dikkat çekmiştir. Farklı teknolojilerin öğrenenlerin duygusal ve bireysel motivasyonları üzerindeki etkileri kaygılara sebep olduğu görülmüştür. Çalışma teknoloji ile geliştirilmiş öğrenme sürecinin başarısı açısından öğretmenin bilgi ve becerisinin önemine dikkat çeken sonuçlar bulurken sorgulama tabanlı öğrenme ve ters yüz sınıf modelinin öğrenme sürecindeki potansiyelleri dikkat çekmiştir.

### Tartışma ve Sonuç

Teknoloji ile desteklenen matematik eğitimi üzerine 2017 ve 2022 yılları arasında Web of Science veri tabanında yayınlanan akademik çalışmalar üzerine yapılan içerik analizi çalışması, mevcut alan yazının genişlemesine katkı sunmaktadır. Bunun yanında bulgularımız Xie ve arkadaşları (2019) ve Sarker ve arkadaşları (2019) tarafından yapılan çalışmaların öğrenme deneyiminin bireyselleştirilmesi ve dijital öğrenme ortamlarında yaşanan zorluklar çerçevesinde benzerlikler gösterirken, özellikle öğrenenlerin duygusal ve motivasyonel gelişimi konusunda benzer sonuçların elde edildiği görülmüştür. Teknoloji ile desteklenen öğrenmenin başarısı noktasında öğretmenin bilgi ve becerisinin önemi Marín ve arkadaşları (2020) tarafından yapılan çalışma ile uyum göstermektedir. Schweighofer ve Ebner (2015), eğitimcilerin sürekli mesleki gelişim göstermelerinin gerekliliğinin altını çizmiştir. Bu çalışmada elde edilen sonuçlar, problem tabanlı öğrenme ve ters yüz sınıf modeli ile öğrenmenin matematik eğitiminde başarılı sonuçlar verdiğini bu durumun yapılandırmacı pedagoji ile uyumlu olduğunu göstermiştir. Ancak, yapılan incelemeler sonucunda alan yazında teknoloji ile desteklenen öğrenme çerçevesindeki çalışmaların katılımcılar ve yöntemsel süreçler hakkında yeterli bilgiyi sunmadığı görülmüştür. Sonuç olarak, bu çalışma teknoloji ve matematik eğitimi arasındaki güçlü ve dinamik bağı bir kez daha ortaya koymakla kalmayıp, gelecek çalışmalar için yeni odak noktalarına da işaret etmektedir. Bu noktada, bu çalışma matematik eğitiminde teknoloji kullanımının daha derin bir şekilde değerlendirilmesi ve anlamlandırılmasının öğrenenlere, öğreticilere ve akademik topluluklara olumlu dönüşler sağlanabileceği görülmüştür.

# *A Content Analysis of Technology Enhanced Learning in Mathematics Education Studies Between 2017 And 2022*

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**Abstract**

*This review critically examines the evolving interface of technology-enhanced learning (TEL) within the realm of mathematics education between 2017 and 2022. Drawing on a detailed content analysis of 23 seminal papers sourced from the Web of Science database, the study seeks to unravel patterns across various dimensions, including geographical distribution, journal prominence, sample characteristics, employed technologies, and foundational learning theories. For this purpose, a classification form, which was developed by researchers based on previous studies, was used to determine the specific knowledge from articles. To better understand the accessed data, the content analysis method has been used on the data which were classified on classification form. The overarching objective remains anchored in discerning prevailing themes and trends that could illuminate future research trajectories and enhance pedagogical design in mathematics. The outcomes underscore dynamic shifts in technological adoption, with certain technologies finding more resonance in mathematical education for varied learner groups. Additionally, the review throws light on the prevalent learning theories guiding these studies, hinting at the pedagogical underpinnings steering this academic discourse. Intended for academics, policymakers, and educators, this study not only maps the current terrain of TEL in mathematics but also delineates the contours for impending explorations, emphasizing the need for more inclusive and exhaustive reviews in the future.*

*Keywords: Technology-enhanced learning, Mathematics education, Content analysis*

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# A Content Analysis of Technology Enhanced Learning in Mathematics Education Studies Between 2017 And 2022

## 1. Introduction

The term "technology-enhanced learning" (TEL), as articulated by Schweighofer and Ebner (2015), serves as an umbrella that encompasses multifaceted approaches wherein technology acts as a pivotal anchor supporting the learning and teaching continuum. This domain contains avenues such as e-learning, game-based learning, flipped classroom approach, inquiry-based learning, and a plethora of other specialized fields (Schweighofer & Ebner, 2015). Lai and Bower (2020) observed the monumental expansion of educational technology research over four decades, evolving from niche corners to a central pedestal in the academic discourse. Such exponential growth has paved the way for a more nuanced investigation into technology's implications beyond just learning outcomes (Lai & Bower, 2020). Yet, for all its advantages, the very magnitude and diversity of literature on technology-enhanced learning present an inherent challenge, making it difficult for researchers to distil coherent trends and patterns. However, systematic literature reviews emerged, offering a structured lens to peruse this expansive field (Lai & Bower, 2020).

Central to the academic journey is the students' agency. Marín et al. (2020) highlight the role of universities in molding graduates who can navigate societal demands innovatively and efficiently. In their view, the design of learning in higher education remains paramount, especially when underpinned by technology-enhanced learning. Digital technology's foray into education is undeniably revolutionary, creating paradigms that transcend traditional spatial and temporal barriers. As highlighted by Sarker et al. (2019), the amalgamation of digital resources, ranging from the internet and mobile devices to analytical software, has democratized access, fostering enriched learning experiences. The shift towards personalizing educational experiences through technology, as noted by Xie et al. (2019), emphasizes the unique individuality of learning trajectories. The rapid strides in information communication technology (ICT) have rendered adaptive and personalized learning a tangible reality.

The terminological landscape that describes the relationship between education and digital technology has been continually evolving over the past decades, revealing much about the field's shifting priorities. Bayne (2014) navigates through this rich tapestry of terms and their historical and geographical context, observing the ebbs and flows in their usage. Initially, terms like ‘ICT for learning’, ‘computer-based learning’, and ‘online education’ gained traction. By the turn of the 21st century, 'learning technology' became the preferred nomenclature, particularly in UK university support units. However, as the first decade progressed, ‘e-learning’ and its variants overshadowed prior terms. Intriguingly, a discernible shift in the UK was the rising prominence of the term ‘technology-enhanced learning’. While this terminology gained momentum in the UK and certain European contexts, its global adoption remained limited. In contrast, terms like ‘instructional technology’, ‘educational technology’, and ‘e-learning’ maintained their dominant stature on the global stage (Bayne, 2014).

The myriad themes that emerge from this review, from student agency to pedagogical design and technological advances, collectively weave a narrative of technology-enhanced learning's transformative potential in mathematics education. Yang et al. (2019) suggested further investigation on technology-enhanced learning in mathematics education in their review on flipped learning in mathematics education in the context of technology-enhanced learning This review delves deep into these facets, exploring the current scene as well as future trends and directions.

As education undergoes unprecedented transformation catalyzed by technological advancements, the field of mathematics stands to benefit remarkably from such shifts. The present review critically evaluates the nexus between mathematics and technology-enhanced learning over the last five years by distilling insights papers sourced from the Web of Science.

The research questions of the study are listed below:

1. What is the distribution of studies on technology-enhanced mathematics learning studies by country?

2. What is the distribution of technology-enhanced mathematics learning studies according to the journals?

3. What is the distribution of the samples in technology-enhanced mathematics learning studies?

4. What is the distribution of the samples in technology-enhanced mathematics learning studies according to their size?

5. Which variables were used in studies related to technology-enhanced mathematics learning studies?

6. What research methods are used in technology-enhanced mathematics learning studies?

7. Which technologies were used in technology-enhanced mathematics learning studies?

8. Which learning theories were used in technology-enhanced mathematics learning studies?

## 2. Method

In this research, content analysis methodology, which is one of the qualitative research methods, is used. In the literature, different definitions of content analysis exist; while Stemler (2001) noted that the previous definition of content analysis is a systematic, replicable, and category-based method, Prasad (2008) drew their definitions from the perspective of communication. According to Prasad (2008), content analysis is a method that determines the presence of certain content included within channels of communication. Due to definitions focused on different perspectives on content analysis, a consensus content analysis needs to be made that can be achieved with durable content. This can be formed with paper-based, audio-visual records or online sources (Prasad, 2008; Stemler, 2001). Thus, it can be argued that content analysis can be used to reach mutual meaning in a group of materials that have a similar or the same purpose, thereby making it an effective tool in our query.

### 2. 1. Data Collection Process

This study used content analysis to understand the nature of technology-enhanced mathematic learning studies with a group of variables. For this purpose, we examined academic journal articles from the Web of Science (WoS) database between 2017 and 2022. In this search, we used “Math Education” + “Technology Enhanced Learning”, “Mathematics Education” + “Technology Enhanced Learning”, “Math Education” + “TEL” and “Mathematics Education” + “TEL” combinations on the WoS. With these search combinations, we accessed 89 journal articles.

Researchers reviewed each paper based on elimination criteria, which examined the relations with mathematics, technology enhancement and education. For this purpose, technology-enhanced mathematics learning classification has been developed by researchers based on "The Educational Technology Publication Classification Form" (Goktas et al., 2012). After each researcher finished the examination, classification forms were compared, and disagreements were discussed to reach a consensus. At the end of this process, 23 academic journal articles have been left to content analysis. The list of the journal articles that have been reviewed can be seen in the appendix section.

### 2.2. Data Analysis

In the data analysis process, a step approach, which has been suggested by Prasad (2008), was followed. In this process, Nvivo qualitative analysis software was used. For the first step, research questions were determined, and then sample selection criteria were settled. Based on the research question and the sample selection criteria, classification categories were chosen, which are outlined and discussed below. This step was followed by coding and thematic analysis of the results, testing, and intercoder discussions resulting in the findings below, providing a summary of the results and analysed data.

## 3. Findings and Discussion

This study analysed studies on technology-enhanced mathematics learning studies between 2017 and 2022. For this purpose, Web of Science indexed journals reviewed with the related papers on technology-enhanced mathematics education studies. In total, 23 papers have been accessed by researchers in the context of this research.

### 3. 1. Distribution of Studies by Countries and Journals

From the 23 papers selected, a significant number of studies were conducted in Europe and Asia, with only a few originating from the Middle East and Central Asia and none from the USA or South America. Although, in total 23 studies were reviewed, some studies have more than one author from different countries or even regions. Therefore, while the number of reviewed papers was 23, the total number of authors was 32.

Table 1 below demonstrates the distribution of the studies’ countries and regions, where it is taken into account that some were published with international collaboration with multiple countries involved. Most studies n=15 (65.2%) were conducted in Europe a breakdown of countries can be seen in Table 1. The topic also received much attention in the Southeast Asian region, with n=9 (39.1%) studies relevant, while n=6 (26.1%) in the Middle East and Central Asia, with much focus from Israel (5 studies), and one in both North America and Africa (4.3%). These results show similarities with previous research. A review on technology-enhanced learning in higher education has been made by Marín, de Benito, and Darder (2020). According to their results, Europe was the leading continent of technology-enhanced learning studies in higher education between 2002 and 2020 (Marín et al., 2020). In another mathematic-related study, Trinh Thi Phuong et al. (2022) made a bibliometric analysis of ICT in Mathematics education Scopus-indexed papers between 1999 and 2020. Their study showed that European countries conducted the most research on this area. This result corresponded to our findings, with a further similarity in that European countries were followed by Asian countries (Trinh Thi Phuong et al., 2022).

**Table 1.**

*Distribution of Papers per Country and Region*

| Region | Country | Number of Studies | Number of Studies |
|---|---|---|---|
| Europe | Austria | 1 | 15 |
| | Belgium | 2 | |
| | Finland | 1 | |
| | UK | 1 | |
| | Portugal | 2 | |
| | Germany | 1 | |
| | Greece | 1 | |
| | Italy | 2 | |
| | Spain | 1 | |
| | Ireland | 2 | |
| | Poland | 1 | |
| Southeast Asia | Taiwan | 3 | 9 |
| | Thailand | 1 | |
| | Malaysia | 1 | |
| | China | 1 | |
| | Hong Kong | 3 | |
| Middle East and Central Asia | Israel | 5 | 6 |
| | Kazakhstan | 1 | |
| Africa | South Africa | 1 | 1 |
| North America | Canada | 1 | 1 |
| Total | 20 | 32 | 32 |

When considering the Journals used for publishing, Table 2 displays a detailed list of target journals and paper numbers, together with the main theme of the journals. Most target journals (n=11) focused on Technology and Education (n=12) papers were included from these journals. N=3 papers were included from journals focusing on education and STEM as a collective, while n=4 from journals with a main focus on education and one particular STEM, eg science, and mathematics. Finally, there were 2 papers included from journals focusing mainly on mathematics, and one from each: assessments and contemporary education.

Further examining the impact factors of these journals in 2023, there is one in the excellent category, while 10 in the good category, with the remaining 9 average, noting that over half (n=12 or 52.2%) papers included within the current study are from high impact journals in the recent year.

**Table 2.**

*Distribution of Papers according to Journals and Themes*

| Journals | 2023 Journal Impact Score | Number of Studies | Journal Themes | Number of Studies |
|---|---|---|---|---|
| Contemporary Educational Psychology | 6.922 | 1 | Education and Technology | 12 |
| Journal of Educational Computing Research | 4.345 | 1 | | |
| Computers & Education | 11.182 | 1 | | |
| Education and Information Technologies | 3.666 | 1 | | |
| Interactive Learning Environments | 4.965 | 2 | | |
| Educational Technology Research and Development | 5.58 | 1 | | |
| International Journal of Child-Computer Interaction | 1.033 | 1 | | |
| Multimodal Technologies and Interaction | 3.17 | 1 | | |
| International Journal of Emerging Technologies in Learning | 3.27 | 1 | | |
| Informatics in Education | 0.956 | 1 | | |
| Journal of Research on Technology in Education | 3.281 | 1 | | |
| International Journal of Mathematical Education in Science and Technology | 1.33 | 2 | Education and STEM | 3 |
| International Journal of STEM Education | 5.789 | 1 | | |
| The International Journal for Technology in Mathematics Education | 2.051 | 2 | Education and Mathematics | 3 |
| ZDM Mathematics Education | 2.481 | 1 | | |
| Cypriot Journal of Educational Sciences | 1.08 | 1 | Education and Science | 1 |
| The Journal of Mathematical Behavior | 0.948 | 1 | Mathematics | 2 |
| Mathematics | 2.592 | 1 | | |
| Frontiers in Education | 2.61 | 1 | Contemporary education | 1 |
| Assessment & Evaluation in Higher Education | 4.44 | 1 | Assessments | 1 |
| Total | | 23 | 7 | 23 |

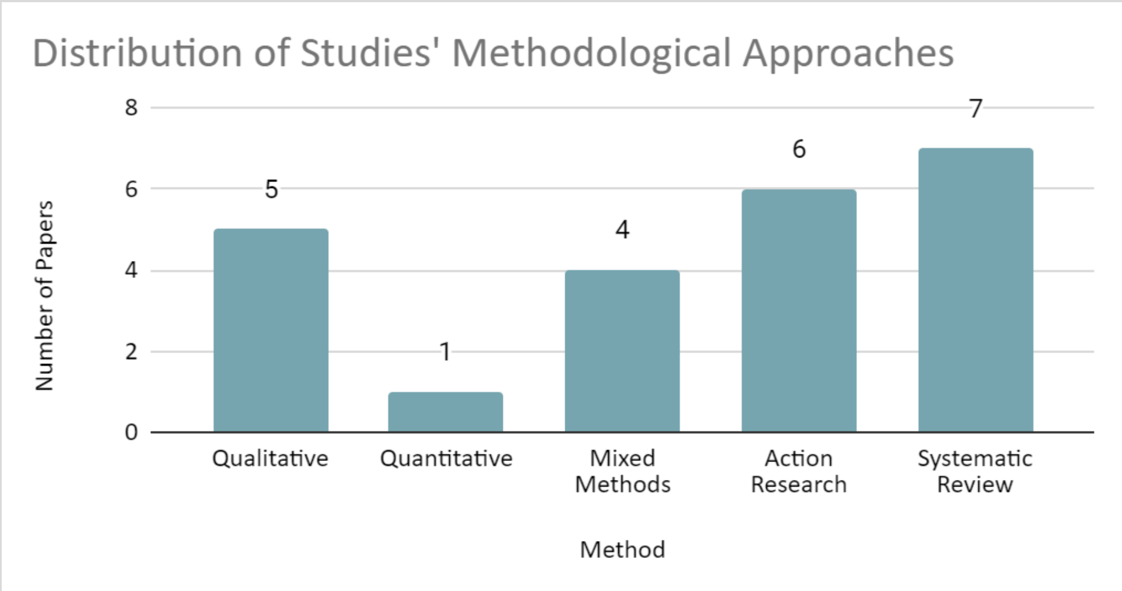
These results show a distinction from the previous results in this research topic. Bray and Tangney's (2017) study shows that in terms of academic journals, previous studies were frequently published in mathematics and mathematics education journals. Also, it can be seen that education and technology-focused journals were listed as others besides more mathematic-related journals. In addition to those journals, it can be seen that the Mathematics Education congresses were also popular for publishing technology-enhanced mathematics studies (Bray & Tangney, 2017). Therefore, it can be said that, throughout the years, technology-enhanced mathematics education papers have found more place in education and technology-focused journals than before.

### 3. 2. Research Methods and Data Collection Tools

Figure 1 demonstrates the distribution of the methodological approaches the studies used in this research. Most papers included were systematic reviews with n=7 (30.4%), then action research projects (n=6 or 26.1%), and finally, qualitative papers (n=5, 21.7%). Other studies adopted a mixed method (n=4 or 17.4%) or quantitative approach (n=1 or 4.3%). A similar result has been found in technology-enhanced learning in higher education review (Marín et al., 2020). Based on their result, for about two decades, reviews were the most common methodological approaches for technology-enhanced learning in higher education, this result was followed by qualitative and mixed-method studies.

**Figure 1.**

*Distribution of Studies' Methodological Approaches*

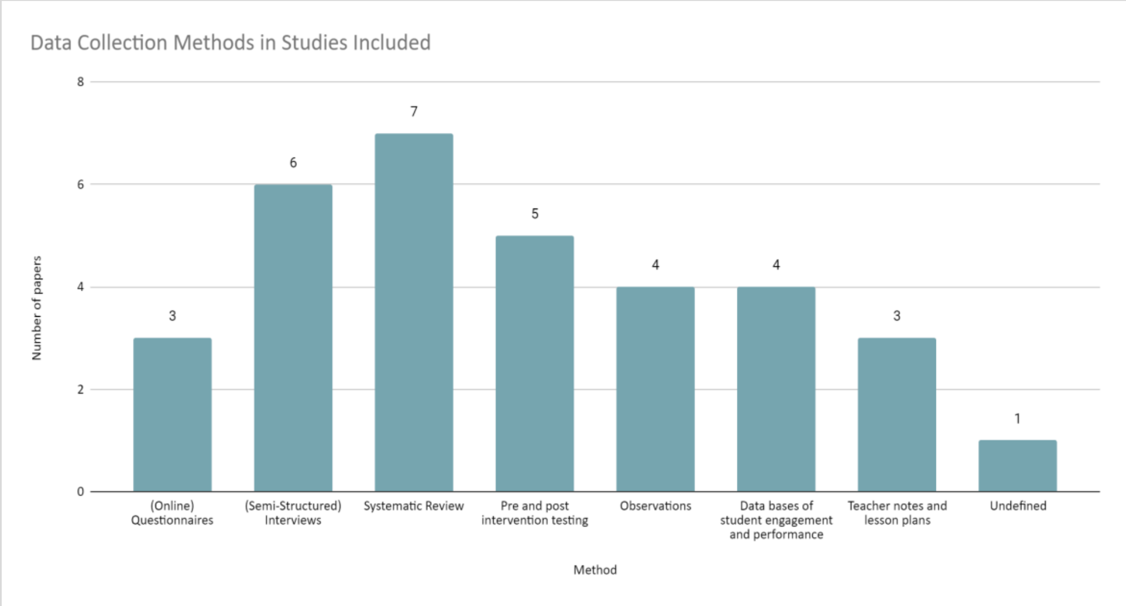



Upon closer examination of these methodological approaches, it is essential to consider data collection methods separately and in connection to the methodological approach. As displayed in Figure 2, most studies used more than one methodological approach. For methodological triangulation to gain more accurate and reliable data, thereby enhancing the validity of findings. N=7 papers used systematic reviews, n=6 used interviews (in most cases, this meant semi-structured interviews), and n=5 applied pre- and post-intervention testing of students to assess the effectiveness of interventions, a method often used in action research projects. Other common methods included n=4 observations and analyzing statistical data collected from virtual learning environments monitoring student engagement and performance. N= 3 studies used questionnaires (online or paper) to collect data, as well as teacher notes and lesson plans. Unfortunately, one study seemed ambiguous regarding its data collection, and a method was not specified. Due to the lack of data on this area, this result cannot be discussed with the previous studies. In the future researchers might consider reviewing data collection methods and tools for studies.

Looking at cross-examining the methodological approaches with the data collection method, it is clear that action research projects were more likely to use pre- and post-intervention comparisons, quantitative studies aggregated statistics, while qualitative studies questionnaires and interviews. Systematic reviews used various methods for collecting the papers included within their meta-analysis, most focusing on specific databases between given dates and with specific keywords defined, including “GeoGebra”, “Dynamic Geometric Software”, “Information Communication”, “Augmented Reality,” etc.

**Figure 2.**

*Distribution of Data Collection Tools Noted in Papers*




### 3. 3. Sample Sizes, Sample Education Levels, and Sample Selection Methods

The sample sizes in the examined papers were largely variable, from large-scale research involving approximately 1,000 students to small-scale studies focusing on one class in a decided school. Table 3 below displays the various sample sizes by participant type and numbers, with one paper unspecified where data originated from. Some studies used more than one participant group for better triangulation of results to gain a better understanding of the central phenomenon this is accounted for in the table below.

**Table 3**.

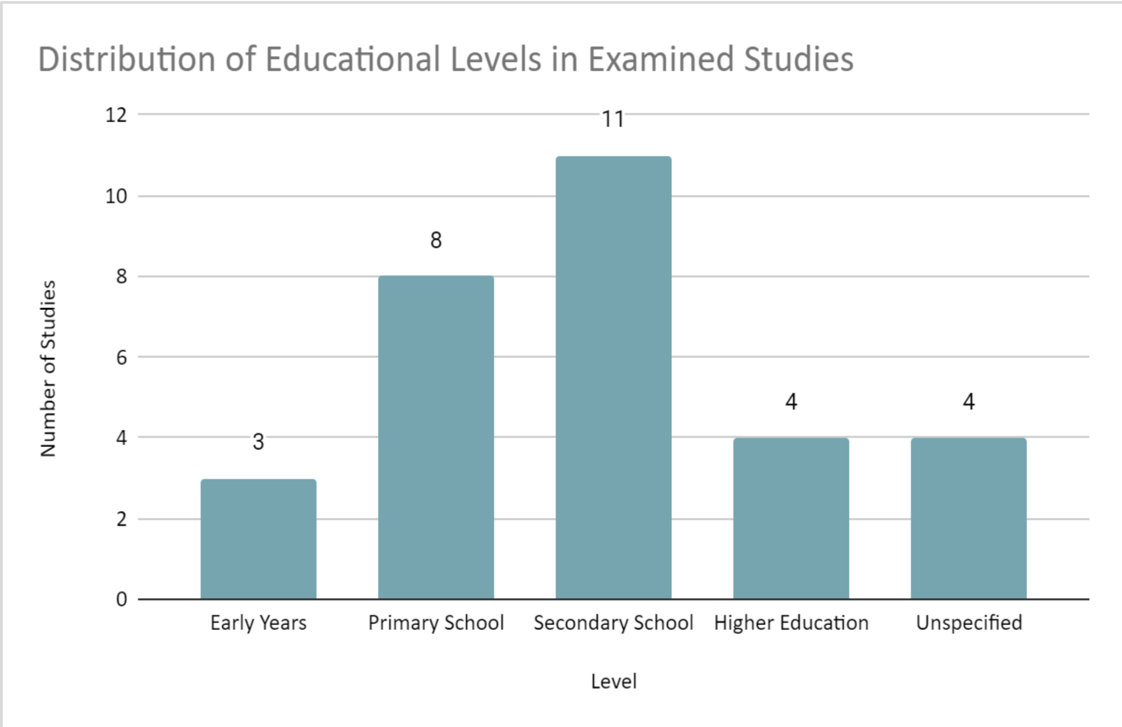
*Sample Sizes in Studies by Participant Type*

| Systematic Review | Students | Teachers | Institutions | Researchers |
|---|---|---|---|---|
| 311 | 1000 | 120 | 7 | 10 |
| 139 | 289 | 80 | 2 | |
| 79 | 174 | 18 | | |
| 54 | 130 | 12 | | |
| 17 | 74 | 7 | | |
| | 33 | 3 | | |
| | 29 | | | |
| | 23 | | | |
| | 8 | | | |
| Total 600 | 1760 | 240 | 9 | 10 |

Upon closer examination of teachers' and students' educational levels, it is evident that research focused on all academic levels from early years up to higher education. Most studies, n=11, included secondary school level participants, with the second most prevalent population sample originating from primary schools, n=8. A smaller number of studies focused both on the early years and higher education, with some studies not specifying an age group or educational level as the focus of the investigation. Again, some studies were conducted through various age groups and academic levels, which must be accounted for when examining Figure 3 below. This result shows a contrast to the study of Xie et al. (2019) about trends in technology-enhanced personalized learning review. In their study, while the higher education students were the biggest personalized technology-enhanced learning group, in total, K-12 group students, which covers both elementary and high school students, were the second biggest group with almost half of the number of higher education and above level participants (Xie et al., 2019). However, Li and Ma's (2010) meta-analysis study about the effects of computers on mathematics learning at the K-12 level shows that almost 37 thousand students participated in 85 different studies. This study displays that bigger groups were possible in technology studies in mathematics education as we found a study with 1,000 participants.

**Figure 3.**

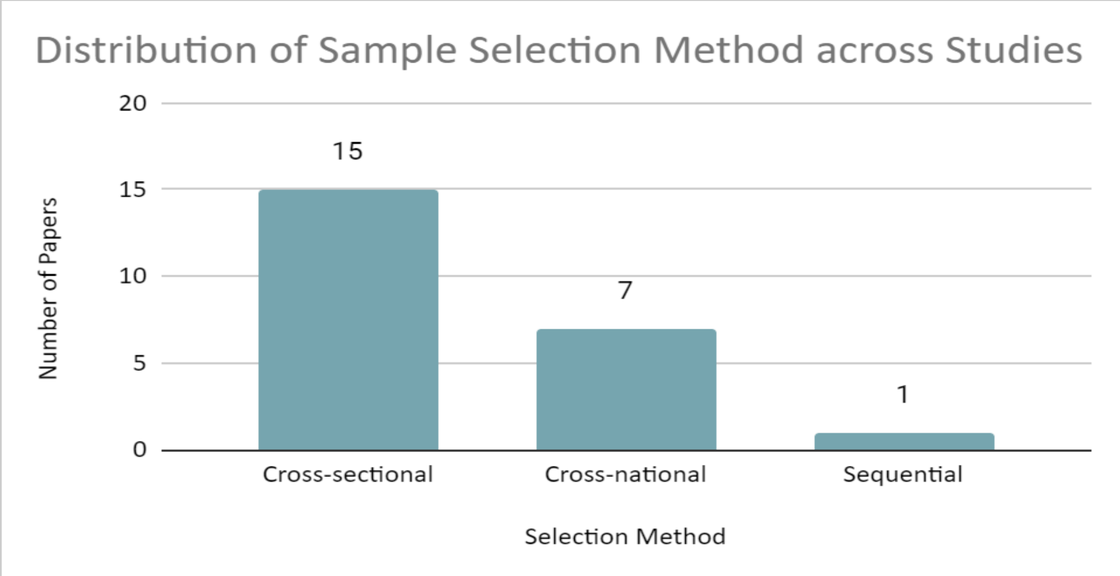
*Distribution of Educational Levels in Examined Studies*




Most studies included were cross-sectional (n=22), looking at the particular samples selected at a specific time, with the action research projects examining them within a short time frame, pre and post-intervention. N=7 of the cross-sectional studies were cross-national, these account for the systematic reviews of literature examining a wide range of papers from multiple regions. One study included was sequential, as noted below in Figure 4. In general conclusion, about the samples on technology-enhanced learning studies in mathematics education, participants and their specifications were reviewed in a few studies. This situation makes it hard to explain the relations between the sample groups and study results.

**Figure 4.**

*Distribution of Sample Selection Methods across Studies Included*




### 3. 4. Variable Types Explored in the Studies

Table 4 shows the distribution of the variables studied in technology-enhanced learning in mathematics studies. Among the 19 variables, it was seen that academic Understanding, which refers to the use of technology to understand mathematics better (n=9), was the most used variable group in TEL studies. Academic achievement was the second common variable in this research. Achievement variables (n=7) have been following usefulness (n=6), engagement (n=4), problem-solving (n=3), attitude (n=3) and feedback (n=3). Computational thinking, cognitive load, and anxiety were other variables but less commonly researched ones. In addition to them, motivation, materials and methods were also fewer common variables for technology-enhanced learning in mathematics studies. Although 23 studies were included in this study, the total number of variables in Table 4 is 49 because some studies used more than one variable.

**Table 4.**

*Distribution of variables*

| Variable | Number of Studies (f) | Percentage (%) |
|---|---|---|
| Understand Mathematics Better | 9 | 18.37 |
| Academic Achievement | 7 | 14.29 |
| Usefulness | 6 | 12.24 |
| Engagement | 4 | 8.16 |
| Problem-solving | 3 | 6.12 |
| Attitude | 3 | 6.12 |
| Feedback | 3 | 6.12 |
| Others | 14 | 28.57 |
| Total | 49 | 100 |

Similar and contrasting results exist in the literature (Borba et al., 2017; Bray & Tangney, 2017). Bray and Tangney (2017) systematically analysed 139 papers about technology use in mathematics education. In their study, understanding the mathematical content and improving the achievement level were leading variables (Bray & Tangney, 2017). Also, in their paper, students' attitude was the third variable which researchers were focused on (Bray & Tangney, 2017). Even though Borba et al., (2017) and Bray and Tangney's (2017) studies were published in the same year, these studies show differences about the variables, which were investigated in previous studies. According to Borba et al., (2017), previous studies were also focused on the usabilities and capabilities of the technologies for mathematics education. These differences might be caused by the samples in which each study has been analysed. The difference can also be caused by the trends in studies from the mid-2010s to late 2010s.

### 3. 5. Learning Theories

Within the realm of technology-enhanced mathematics education studies, many learning theories come to the forefront. Among these theories, constructivism (n=15) stands out as the prevailing cornerstone, supported by its various sub-theories. The significance of constructivism lies in its role in shaping pedagogical strategies for technology-integrated learning environments. The focus on active learner engagement, collaborative learning, and experiential approaches aligns seamlessly with constructivism's principles, resulting in a deeper understanding and long-term retention of mathematical concepts. In the majority of cases, constructivism takes centre stage. However, it is worth noting that behaviourism continues to exert its influence within a singular study. While its utilization is limited, behaviourism’s principles of reinforcement and structured learning inform instructional methodologies, contributing to an enhanced understanding of mathematical concepts within this specific context. Collectively, these dynamics enrich the landscape of technology-enhanced mathematics education studies.

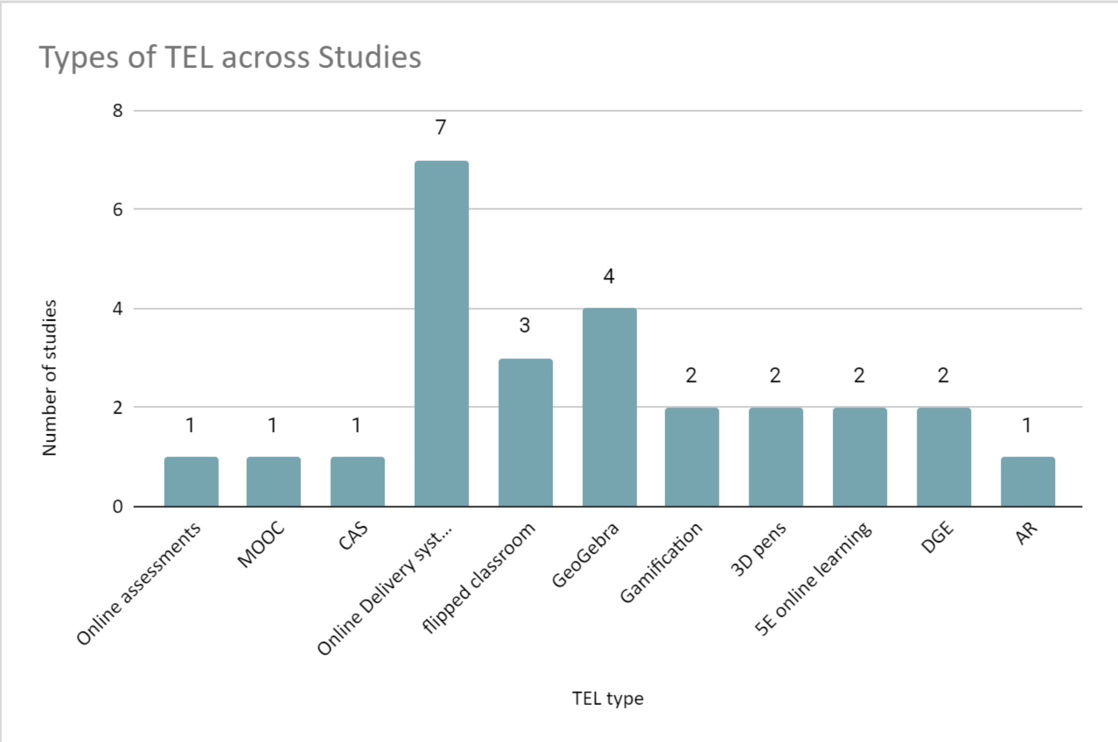
These results show similarities with the previous studies. Bray and Tangney (2017) reviewed technology usage in mathematics education between 2013 and 2016. According to their results, in that term, constructivist pedagogy was the most used pedagogical approach in those studies. Like these results, behaviourist pedagogy was the least used pedagogical approach in those studies (Bray & Tangney, 2017). Also, similar results were shown in Svela, Nouri, Viberg and Zhang's (2019) systematic review. In their study, academic articles that used certain technologies between 2010 and 2018 were reviewed systematically. According to their results, constructivist pedagogy was the leading pedagogical practice in their sample (Svela et al., 2019). As a result, it can be said that constructivist pedagogy has been holding its position for years.

### 3. 6. Technologies Used in Studies

Figure 5 below displays the various TEL types utilized in the studies considered. Online delivery systems were most commonly used, often combined with a flipped classroom approach (n=3) or with gamification (n=2). Although considered separately, online delivery systems may include using MOOC (massive open online courses) as well as CAS. Another commonly used software included GeoGebra (n=4), often used together with other dynamic geometric environments (DGE, n=2) and 3D pens (n=2), taking a constructivist pedagogic approach to learning. These tools allow students to create and visualize geometric concepts. Thereby facilitating the acquisition of knowledge and understanding. Only one study considered the use of AR in mathematics teaching, with further not specifying a particular type of TEL tool. Finally, n=2 studies considered the 5E online learning environment that utilizes the 5E instructional model: engage, explore, explain, extend, and evaluate. This result has similarities and differences with previous research. Due to the different perspectives, each study categorized and defined technologies differently; therefore, while there are some similarities, some differences exist. According to Lai and Bower (2019), Mixed Technologies and Mobile Technologies were the leading technology groups in technology-enhanced learning studies between 2009 and 2018. However, mixed technologies could include mobile technologies as well, so mobile technologies could be the leading technological tools in that era. In another study with a similar period, Xie et al. (2019) traditional computers were the most used technology. However, Marín et al. (2020) found out that, for a wider period, which covers from the early 2000s to late 2010s, Web 2.0 technologies, which cover different online delivery tools, were the most common technologies. This result shows that online delivery tools, which were the leading technology in this study, were also trendy for a greater period.

**Figure 5.**

*Types of TEL*




### 3. 7. Results of the Studies Conducted in Technology Enhanced Learning

Conducting thematic analysis using NVivo to gain a better understanding of the results of these studies, 11 central themes were identified, with implications for practice. Overall, the studies do emphasize the benefits of TEL in the teaching and learning of mathematics, but it is important to focus on all aspects, including enjoyment, engagement, cognitive and emotional aspects of learning, feedback quality, as well as teacher training and overall positive impact on learning.

Enjoyment and Student Attitude towards technology-enhanced learning were one of the most prominent themes, with many studies highlighting the positive impact on learning outcomes, and how user enjoyment outweighs the perceived usefulness of tools when it comes to enjoyment. Gamification and Augmented Reality were also highlighted as positive contributors to learning motivation, as well as enhanced performance, especially with factors such as user personalisation of the learning journey. However, some concerns were raised about the effectiveness of gamification as well as enhancing emotional aspects and personal motivation, thereby addressing not only the Cognitive but also Affective Aspects of Learning. In connection, Learner Empowerment and Active Learning were another key theme, exploring how students can create their knowledge actively using technology in the classroom at their own pace, which led to another key theme, Constructivism in the Classroom. A constructivist pedagogy can enable the development of higher-order skills, and as highlighted by studies, it is a preferred approach, especially when teaching visual aspects such as geometry (as seen in studies utilizing GeoGebra, 3D pens, and DGEs).

A potential Positive Association with online learning environments was found in connection to mathematical learning, however, there are issues with the generalisability of these results to other domains, populations and learning environments, with a particular need to address biases and intrinsic motivations to learn. When exploring students' understanding, motivation, and meeting of learning outcomes, it was found that TEL has an Impact on Achieving Learning Outcomes, as it not only helps realise these goals but also enhances students' problem-solving and reasoning skills. Other Transferable Skills Development was also associated with TEL, such as teamwork, especially when considering immersive technologies and gamification.

Nonetheless, Teacher Knowledge and Training can be problematic when it comes to TEL, As noted by a significant number of studies, the success of any TEL in the classroom largely depends on the knowledge of teachers, which calls for both, a need for constant upskilling of teachers, and the implementation of TEL and related pedagogy in any teacher training programmes. These initial changes could pose issues with staff workload and time management. However, the prospective long-term benefits may have the potential to outweigh these limitations. To further these points, it has also been found that the effectiveness of TEL may also depend on good Quality Feedback provided by teachers and instructors. The COVID-19 pandemic significantly increased the use of TEL around the world, but it has also drawn out systematic issues with the current system, including providing feedback, which needs to be addressed to enable successful TEL in classrooms. A potential approach may be to implement Inquiry-Based Learning and Flipped Classroom learning, where teachers and instructors are given the opportunity for one-to-one or small-group interactions to provide feedback and explore areas where students may need more guidance. These approaches were seen as effective strategies in mathematical learning and teaching, although they need further evaluation to be validated.

## 4. Conclusion and Suggestions

In this research, the studies about technology-enhanced mathematics learning studies between 2017 and 2022, with the help of various variables are examined, and the current situation is revealed.

The content analysis results show that, throughout the years, technology-enhanced learning studies changed in some aspects, while other study features kept track similar to previous studies. In this context, while the learning theories, variables, which were studies in studies, and methodology-related study features kept a related track with previous studies, technologies were changed parallel to technological developments. However, it has been seen that some of the research features were not studied in previous reviews. One of the important ones is the samples. Unfortunately, technology-enhanced mathematics learning study reviews did not pay attention to participants and their features. Also, as part of the methodological structure, data collection tools did not catch the attention of researchers who conducted reviews in this area.

In conclusion, it can be said that different technologies have found usage areas in mathematics education for different learners. In the future, to improve the quality of technology-enhanced mathematics education, further reviews can be conducted, particularly with the emergence of artificial intelligence (AI) and intelligent, personalized tutoring. In those reviews, participants, both hardware and software technologies, digitalization of the materials, and meta-analytic results can be researched further, as well as AI and its role in the learning and teaching of mathematics.

**Conflict of Interest**

The authors declare that there is no conflict of interest with any institution or person within the scope of the study.

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**Ethical Approval**

The authors declare that their work is not subject to ethics committee approval and that the rules set by the Committee on Publication Ethics (COPE) were followed throughout the study.

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## Appendix

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