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Inclusive Mathematics Education and Down Syndrome: Cognitive Foundations and Evidence-Based Teaching Recommendations

Fatma Erdoğan[1], Sinan Kalkan[2]

[1]Department of Mathematics and Science Education, Faculty of Education, Fırat University, Elazığ, Türkiye,
f.erdogan@firat.edu.tr ORCID: 0000-0002-4498-8634
[2]Department of Special Education, Faculty of Education, Çanakkale Onsekiz Mart University, Çanakkale, Türkiye,
sinan.kalkan@comu.edu.tr ORCID: 0000-0001-6890-6421

Corresponding Author: Fatma Erdoğan

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Kapsayıcı Matematik Eğitimi ve Down Sendromu: Bilişsel Temeller ve Kanıta Dayalı Öğretim Önerileri

Fatma Erdoğan[1], Sinan Kalkan[2]

[1]Matematik ve Fen Bilimleri Eğitimi Bölümü, Eğitim Fakültesi , Fırat Üniversitesi, Elazığ, Türkiye,
f.erdogan@firat.edu.tr ORCID: 0000-0002-4498-8634
[2]Özel Eğitim Bölümü, Eğitim Fakültesi, Çanakkale Onsekiz Mart Üniversitesi, Çanakkale, Türkiye,
sinan.kalkan@comu.edu.tr ORCID: 0000-0001-6890-6421

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Etik Not: Araştırma ve yayın etiğine uyulmuştur. Çalışmanın kapsamı ve yöntemi nedeniyle etik kurul izni gerekmemiştir.

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[1]*Department of Mathematics and Science Education, Faculty of Education, Fırat University, Elazığ, Türkiye,* *f.erdogan@firat.edu.tr* *ORCID: 0000-0002-4498-8634*
[2]*Department of Special Education, Faculty of Education, Çanakkale Onsekiz Mart University, Çanakkale, Türkiye,* *sinan.kalkan@comu.edu.tr* *ORCID: 0000-0001-6890-6421*

Abstract

This review study addresses the strengths and limitations in the mathematical abilities of children with Down syndrome (DS) from an inclusive education perspective. Within the framework of research in the field of inclusive mathematics education, theoretical and practice-oriented insights have been derived to better understand the mathematical development of these children. In particular, the effects of difficulties in linguistic processing, verbal memory, and executive functions on their mathematical learning processes have been discussed. At the same time, it has been highlighted that relative strengths in areas such as visuospatial attention can be transformed into educational opportunities when supported by appropriate instructional strategies. Thematic analyses are presented based on studies focusing on multi-dimensional mathematical skills such as counting, cardinality, numerical estimation, and non-symbolic processing. Furthermore, the role of digital tools and game-based instructional approaches in inclusive education is emphasized, and evidence-based instructional recommendations are outlined. In conclusion, the literature points to the significant potential of individualized, multisensory, visually supported, and structured teaching methods in enhancing both the academic achievement and functional life skills of children with DS.

Article Info

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Kapsayıcı Matematik Eğitimi ve Down Sendromu: Bilişsel Temeller ve Kanıta Dayalı Öğretim Önerileri

Öz

Bu derleme çalışması, Down sendromlu (DS) çocukların matematiksel becerilerindeki güçlü ve sınırlı yönleri kapsayıcı eğitim perspektifiyle ele almıştır. Kapsayıcı matematik eğitimi alanındaki araştırmalar çerçevesinde, bu çocukların matematiksel gelişimini daha iyi anlamaya yönelik kuramsal ve uygulamaya dönük çıkarımlara ulaşılmıştır. Özellikle, DS'li çocukların dilsel işlemleme, sözel bellek ve yürütücü işlevlerde yaşadıkları güçlüklerin matematik öğrenme süreçleri üzerindeki etkileri tartışılmıştır. Bununla birlikte, görsel-uzamsal dikkat gibi göreli güçlü yönlerin uygun öğretim stratejileriyle desteklendiğinde eğitsel fırsatlara dönüştürülebileceğine dikkat çekilmiştir. Sayma, kardinalite, sayısal tahmin ve sembolik olmayan işlemleme gibi çok boyutlu matematiksel beceriler bağlamında yapılan çalışmalar üzerinden tematik analizler sunulmuştur. Ayrıca, dijital araçlar ve oyun temelli öğretim yaklaşımlarının kapsayıcı eğitimdeki yeri vurgulanarak, kanıta dayalı öğretim stratejilerine yönelik çıkarımlar yapılmıştır. Sonuç olarak, literatürde bireyselleştirilmiş, çok duyulu, görsel destekli ve yapılandırılmış öğretim yöntemlerinin, DS'li çocukların hem akademik başarılarını hem de işlevsel yaşam becerilerini geliştirmede önemli bir potansiyele sahip olduğuna dikkat çekilmiştir.

Makale Bilgisi

Anahtar Kelimeler: Down sendromu, matematik eğitimi, sayısal beceriler, zihinsel yetersizlik, kapsayıcı eğitim

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İletişim/Contact: f.erdogan@firat.edu.tr
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Geniş Özet

Matematiksel yeterlilik, bireylerin bilişsel gelişiminin yanı sıra günlük yaşama katılımında da temel bir rol oynamaktadır. Problem çözme, zaman yönetimi, alışveriş ve karar verme gibi birçok günlük beceri matematiksel bilgiye dayanır. Bu nedenle matematik eğitimi yalnızca akademik bir zorunluluk değil, aynı zamanda sosyal adalet ve insan haklarına dayalı bir eğitim politikası olarak görülmelidir. Down sendromlu (DS) çocukların matematiksel gelişimi incelendiğinde, yalnızca zihinsel yetersizlik değil; dikkat, sözel bellek, dilsel işlemleme ve yürütücü işlevlerdeki güçlüklerin de öğrenmeyi etkilediği anlaşılmaktadır. Bununla birlikte, görsel-uzamsal beceriler gibi göreli güçlü yönler uygun öğretimle akademik kazanıma dönüştürülebilir. Bu çalışmanın amacı, DS'li çocukların matematiksel gelişim özelliklerini ve karşılaştıkları bilişsel güçlükleri kapsayıcı eğitim anlayışı çerçevesinde ele almak; bu çocukların sayı kavramı, sayma, tahmin, karşılaştırma ve işlem yapma gibi temel matematiksel becerilerindeki güçlü ve sınırlı yönleri güncel bilimsel veriler ışığında değerlendirmektir. Ayrıca, görsel, oyun temelli ve teknoloji destekli öğretim stratejilerine dayalı uygulama önerileri sunularak, DS'li çocukların matematiksel öğrenme süreçlerinin daha işlevsel ve erişilebilir hale getirilmesine katkı sağlanması hedeflenmektedir.

Zihinsel Yetersizlik Bağlamında Kapsayıcı Matematik Eğitimi

Eğitim, bireylerin yalnızca bilgi edinmesini değil, toplumsal yaşama aktif katılımını da sağlayan temel bir araçtır. Bu nedenle birçok ülke eğitime öncelik verirken, özel gereksinimli bireylerin eğitimi yüksek maliyet ve sürdürülebilirlik açısından özel önem taşır. Kapsayıcı eğitim, tüm bireylerin eşit öğrenme fırsatlarına erişimini hedefleyen ve hem pedagojik hem de hukuki temellere dayanan bir yaklaşımdır. Türkiye'de bu yaklaşım yasal düzenlemelerle desteklenmektedir. Zihinsel yetersizliği olan çocuklar için matematik öğretimi, yalnızca akademik başarı değil, aynı zamanda bağımsız yaşam becerileri açısından da önemlidir. Araştırmalar bu çocukların matematikte akranlarının gerisinde kaldığını, ancak kapsayıcı modellerin olumlu etkiler yarattığını göstermektedir. Bu nedenle, öğretmenlerin farklılaştırılmış içeriklere erişimi sağlanmalı, bireyselleştirilmiş öğretim stratejileri uygulanmalı ve kapsayıcı eğitimin politika, mevzuat ve öğretmen eğitimi boyutlarıyla bütüncül şekilde desteklenmesi gerekmektedir. Özellikle DS'li çocuklar, özgün bilişsel özellikleri nedeniyle özel dikkat gerektiren bir gruptur.

DS'li Çocukların Öğrenmesini Etkileyen Gelişimsel Özellikler

DS, trisomi 21 olarak da bilinen genetik temelli bir duruma işaret eder ve bilişsel gelişim üzerinde belirgin etkileri vardır. DS'li çocuklar genellikle bilgi işleme hızında yavaşlama, kısa süreli bellek sınırlılığı, dil gelişiminde gerilik ve işitsel öğrenme zorlukları gibi özellikler sergiler. Ancak görsel bellekleri görece güçlüdür ve bu durum, görsel destekli materyallerin öğrenmede daha etkili olmasını sağlar. Aynı zamanda sosyal açıdan oldukça motive olan bu çocuklar, gözlem yoluyla öğrenme konusunda da avantajlara sahiptir. Bu sosyal yön, kapsayıcı ortamlarda aktif katılımlarını desteklemektedir. Yine de öğrenme sürecinde bireysel farklılıklar oldukça belirgindir; bu nedenle esnek, öğrenciye özgü öğretim planlamaları gereklidir.

DS'li Çocuklarda Matematiksel Gelişim: Bireysel Farklılıklar ve Öğrenme Potansiyeli

DS'li çocukların matematiksel gelişimi, başarı düzeyleri kadar öğrenme stilleri, dikkat süresi, işlem hızı ve kavramsal anlama açısından da büyük çeşitlilik göstermektedir. Bu heterojen yapı, matematik öğretiminde bireyselleştirilmiş yaklaşımların önemini ortaya koymaktadır. Matematik, DS'li çocuklar için yalnızca akademik değil, aynı zamanda günlük yaşam becerileri açısından da temel bir alandır. Geçmişte bu çocukların matematiksel potansiyeline dair olumsuz görüşler yaygınken, son yıllarda yapılan araştırmalar onların cebir, geometri ve grafik yorumlama gibi ileri düzey içeriklere erişebildiğini ve uygun öğretimle karmaşık işlemleri gerçekleştirebildiklerini göstermektedir. Ancak araştırmalar hâlâ çoğunlukla sayı kavramı, sayma ve aritmetik gibi temel alanlara odaklanmakta; bu alanlarda DS'li çocuklar yaş ve zihin yaşına göre geride kalmaktadır. Bu nedenle, sayısal becerilere ilişkin daha derinlikli ve kapsamlı anlayışların geliştirilmesi gerekmektedir.

Sembolik Olmayan Sayısal Beceriler ve Büyüklük Algısı

Sayı kavramı yalnızca sembollerden ibaret değildir; insan bilişi, doğuştan gelen iki sistemle miktarları temsil eder: Nesne Takip Sistemi (OTS) ve Yaklaşık Sayı Sistemi (ANS). OTS, az sayıdaki nesneyi hızlıca algılamayı sağlarken; ANS, daha büyük miktarları oransal farklılıklara göre karşılaştırmaya imkân verir. Araştırmalar, DS'li çocukların OTS'ye dayalı küçük grup karşılaştırmalarında daha yavaş ve düşük doğrulukla performans sergilediklerini; ancak ANS'ye dayalı görevlerde yaşlarına uygun başarı gösterdiklerini ortaya koymuştur. Özellikle oran farkına duyarlılık, DS'li çocuklarda da gözlenmiş ve bu durum, ANS işlevselliğinin büyük ölçüde korunduğuna işaret etmiştir. Bu bulgular, sembolik sayı kavramlarında zorluk yaşayan DS'li çocukların, yaklaşık büyüklükleri algılama becerilerinin öğretimde etkili biçimde kullanılabileceğini göstermektedir.

Sayısal Tahmin Becerileri

Sayısal tahmin, sayıları doğru biçimde temsil etmeye dayalı bir beceridir ve genellikle "sayı-pozisyon (NTP)" görevleriyle ölçülür. DS'li çocuklar küçük sayılarla sınırlı aralıklarda doğru tahminler yapabilse de sayı aralığı genişledikçe (örneğin 0–100), logaritmik hata örüntüleri gözlenmektedir. Bu durum, daha büyük sayılara dair deneyim eksikliği ve görsel stratejileri yeterince kullanamamaktan kaynaklanır. Öğretimde, 1–20 gibi dar aralıklı NTP görevleri hem öğretim aracı hem de tanılayıcı değerlendirme aracı olarak önerilmektedir.

Sayma ve Kardinalite Anlayışı

Sayma, sıralı sayı adlarını nesnelere atayarak toplamı belirleme işlemidir. Kardinalite, sayma sürecinde son söylenen sayının toplam miktarı ifade ettiğini anlamaktır. DS'li çocuklarda sayma becerileri, yalnızca sayı dizilerini ezberlemekten ibaret olmayıp, kavramsal anlayış gerektiren kardinalite ilkesini de içerir. Bu çocuklar genellikle sayı dizilerini tekrar edebilseler de son söylenen sayının toplam miktarı ifade ettiğini anlamakta zorlanabilirler. Araştırmalar, kısa nesne gruplarında (3–5) kardinalite ilkesini uygulayabildiklerini; ancak daha uzun dizilerde dikkat, bellek ve işlemleme kapasitesi sınırlılıklarının performansı düşürdüğünü göstermektedir. Sayma becerileri dil gelişimi, dikkat süresi, işleyen bellek ve motivasyon gibi bilişsel süreçlerle yakından ilişkilidir. Sayma hataları arasında eksik sayma, tekrar etme ve sıra karışıklıkları sık görülür. Bu nedenle öğretim süreci, çocuğun hızına uygun, görsel ipuçları içeren ve dikkat sürelerini destekleyen biçimde yapılandırılmalıdır. Örneğin, eşleştirme kartları, sıralama oyunları gibi araçlar öğrenmeyi destekleyebilir. Başarılı bir öğrenme için çok boyutlu ve bireyselleştirilmiş öğretim yaklaşımları gereklidir.

DS'li çocuklarda Aritmetik Beceriler: Bilişsel ve Gelişimsel Boyutlar

DS'li çocukların aritmetik becerileri, genel bilişsel kapasitelerinden beklenenden daha düşük düzeyde olabilmekte ve bu durum gelişimsel diskalkuli ile ilişkili olabileceği şeklinde yorumlanmaktadır. Sayı tanıma ve okuma gibi alanlarda daha güçlü performans sergileyebilen DS'li çocuklar, özellikle dil gelişimi, sözel kısa süreli bellek ve sayı bilgisine dayalı işlemlerde belirgin güçlükler yaşamaktadır. Sözel bellek ve dikkat eksiklikleri, çok adımlı işlemlerin yürütülmesini zorlaştırırken; görsel-uzamsal becerilerinin görece güçlü olması, somut araçlarla desteklenen öğretim materyallerine daha iyi yanıt vermelerine olanak tanır. Ancak aritmetik bilgi ve becerilerin gelişimi için gereken yoğun tekrar fırsatlarının sınırlı olması, öğrenmeyi olumsuz etkileyebilir. Aritmetik performans, yalnızca yaşla değil; görevlerin zorluk düzeyi, bireysel farklılıklar, motivasyon ve öğrenme ortamının niteliğiyle de yakından ilişkilidir. Ayrıca yaş ilerledikçe işlem yapma güçlüklerinin arttığı gözlenmiştir. Bu nedenle, DS'li çocuklara yönelik aritmetik öğretimi, bilişsel sınırlılıkları gözeten, hedeflenmiş müdahalelerle yapılandırılmış ve bireysel ihtiyaçlara göre uyarlanmış stratejiler içermelidir.

Uygulamaya Yönelik Kanıta Dayalı Öneriler

DS'li çocukların matematikte yaşadığı zorluklar yalnızca zihinsel sınırlılıklardan değil, dikkat, bellek, işlemleme hızı ve motivasyon gibi bilişsel ve duyuşsal etkenlerden de kaynaklanmaktadır. Bu nedenle öğretim süreci, bireysel ihtiyaçlara göre yapılandırılmış, etkileşimli ve çok duyulu yaklaşımlar üzerine kurulmalıdır. Görsel, işitsel ve dokunsal uyaranlar içeren öğrenme ortamları; çocukların sosyal güçlü yönlerine dayalı olarak tasarlanmalı, etkileşimli dijital araçlarla desteklenmelidir. DS'li çocukların görsel destekli anlatımlardan daha fazla yarar sağladığı, buna rağmen sınıf içinde sözlü açıklamaların fazla ağırlık kazandığı belirtilmektedir. Temel matematik becerileri için renk, şekil ve boyuta göre sıralama gibi oyun temelli etkinlikler erken yaşta kavramsal gelişimi destekleyebilir. Ayrıca, yaklaşık sayı sistemi (ANS) temelli etkinlikler, bu çocukların daha iyi performans sergilediği alanlar olup, oran farklarına dayalı görsel materyallerle desteklenmelidir. Sayı doğrusu görevleri (NTP) gibi tahmin etkinlikleri de hem öğretim aracı hem tanılayıcı görevler olarak önerilmektedir. Sayma öğretimi, ezberin ötesine geçerek kardinalite kavramını (son sayının toplamı temsil ettiğini anlama) kazandırmayı hedeflemeli; dokunma, görme ve dinleme gibi çoklu duyulara hitap eden tekniklerle desteklenmelidir. Aritmetik öğretimi ise, önce sezgisel ve görsel temelli görevlerle başlamalı, sonra sembolik işlemlere kademeli olarak geçmelidir. Oyun temelli ve dijital uygulamalar, dikkat ve motivasyonu artırarak öğrenmeyi desteklerken, başarılı sonuçlar ancak dikkatli tasarım ve yapılandırılmış geribildirimle elde edilebilir. "Maths For Life" gibi bireyselleştirilmiş programlar, DS'li çocukların matematiksel gelişiminde anlamlı katkılar sağlayan örnekler arasındadır.

Sonuç

Bu derleme çalışması, DS'li çocukların matematiksel öğrenme süreçlerine çok boyutlu bir perspektifle yaklaşmakta; bilişsel özelliklerini, güçlü yönlerini ve öğrenme potansiyellerini dikkate alan bir öğretim anlayışını savunmaktadır. DS'li çocukların matematik öğrenme süreçlerinin yalnızca genel zihinsel sınırlılıkla açıklanamayacağı, sözel bellek, dikkat ve dilsel işlemleme gibi özgül bilişsel zorlukların da belirleyici olduğu vurgulanmakatdır. Bu bağlamda, görsel-uzamsal beceriler, sosyal motivasyon ve oransal algı gibi göreli güçlü yönler, etkili öğretim stratejileriyle öğrenme

fırsatlarına dönüştürülebilir. Sonuç olarak, DS'li çocuklara yönelik matematik eğitimi hem bireysel gelişim hem de kapsayıcı eğitim politikalarının uygulanabilirliği açısından stratejik bir öneme sahiptir. Bu bağlamda, disiplinler arası, kuramsal temelli ve uygulama odaklı modellerin eğitime entegre edilmesi gerekmektedir.

Introduction

Mathematical competence plays a fundamental role not only in individuals' cognitive development but also in their participation in social life. In particular, a significant portion of essential everyday skills-such as problem-solving, time management, shopping, planning, and decision-making-rely heavily on mathematical knowledge and procedural fluency (Faragher & Clarke, 2020). Furthermore, ensuring individuals' access to mathematics education should not be regarded merely as an academic obligation. Rather, it must be considered a comprehensive educational policy grounded in the principles of social justice and human rights (Karpava, 2025).

When examining the mathematical development of children with intellectual disabilities, such as those with Down syndrome (DS), a rather complex and multidimensional picture emerges (Gilligan-Lee et al., 2025). Although children with DS generally exhibit delays in cognitive development, it is not solely the limitation in mental capacity that affects their mathematical learning processes. In addition, specific challenges in attention, verbal memory, linguistic processing, and executive functioning also play a significant role (Fidler et al., 2006; Grieco et al., 2015). Nevertheless, it is also well established that children with DS can demonstrate meaningful progress in mathematical reasoning and problem-solving skills, particularly when effective instructional strategies are employed. This is especially true considering their relatively stronger performance in certain cognitive domains, such as visuospatial abilities (Lanfranchi et al., 2022; Simms et al., 2020).

In recent years, advancements in developmental cognitive science have elucidated the fundamental systems underlying numerical thinking and the cognitive patterns associated with numerical magnitude representation in a more precise manner (Feigenson et al., 2004; Sella et al., 2021). As a result, the question of how these systems function in individuals with intellectual disabilities, and how mathematics instruction should be structured accordingly, has given rise to a new and multidisciplinary field of inquiry within the educational sciences. The present study aims to examine the characteristics of mathematical development and the cognitive challenges encountered by children with DS within the framework of inclusive education. More specifically, it seeks to evaluate the strengths and limitations of these children in fundamental mathematical skills-such as number sense, counting, estimation, comparison, and computation-based on current scientific evidence. Moreover, by proposing practice-oriented recommendations that incorporate visual, play-based, and technology-supported instructional strategies, the study aspires to contribute to making mathematical learning processes more functional and accessible for children with DS.

Inclusive Mathematics Education in the Context of Intellectual Disability

Education is not only a means of acquiring knowledge, but also a fundamental tool that enables individuals to participate actively in social life. For this reason, many countries prioritize education as a strategic objective and allocate a significant portion of their budgets to this sector (Karpava, 2025). However, within these investments, the education of individuals with special needs stands out due to its high cost and requirements for sustainability. Support programs tailored to developmental differences are considered not only as tools for individual development, but also as long-term societal investments aimed at reducing public expenditures over time (Faragher & Clarke, 2020). In this context, inclusive education represents a holistic approach that emphasizes equal access to learning opportunities for all individuals, regardless of their differences, within the same educational environment. Today, this approach occupies a central position in global education policies (Schnepel et al., 2024). It is regarded not only as a pedagogical necessity, but also as a human rights obligation, and has been guaranteed at the level of international law by Article 24 of the United Nations Convention on the Rights of Persons with Disabilities (UNCRPD) (United Nations, 2006). In Türkiye, this framework has acquired a concrete legal foundation through Law No. 5378 on the Rights of Persons with Disabilities (Grand National Assembly of Türkiye, 2005), Türkiye's ratification of the UNCRPD, and the Regulation on Special Education Services by the Ministry of National Education (2018). In this way, inclusive education has evolved from a guiding principle into a functional and implementable education policy.

Within the scope of inclusive education, mathematics instruction can be defined as an approach that aims not only to support academic achievement, but also to enhance independent living skills for all children with special needs, particularly those with intellectual disabilities (Özdemir & Toptaş, 2023). Accordingly, basic numerical skills are considered critically important for performing everyday functions such as shopping, time management, and the use of money (Stefanelli et al., 2021). These abilities have a direct impact on an individual's autonomy and overall quality of life. Lanfranchi et al. (2021) emphasize that mathematical competence is not merely an academic achievement, but also a foundational skill for social participation and environmental adaptation. Therefore, mathematics education constitutes an essential tool for individuals with special needs (Yılmaz-Yenioğlu & Sönmez-Kartal, 2023).

Nonetheless, research consistently indicates that children with intellectual disabilities tend to perform below their peers in mathematics, which highlights shortcomings in current instructional practices (Bouck & Long, 2023; Özdemir & Toptaş, 2023; Schnepel et al., 2024). However, inclusive education models implemented in recent years have demonstrated that meaningful progress in mathematical development is indeed achievable for these students (Schnepel et al., 2024). Moreover, inclusive classroom environments have been reported to enhance social interaction, support diverse learning styles, and foster a more positive and cohesive classroom climate for both students with special needs and their typically developing peers (Roos, 2019).

Improving the mathematical achievement of children with intellectual disabilities requires enhancing teachers' access to differentiated instructional content and resources (Barr & Mavropoulou, 2019; Schnepel et al., 2024). Due to variability in learning pace and conceptual understanding, individualized educational programs are often more effective and sustainable (Türel & Akgün, 2021). Recent research highlights the value of tailoring interventions to students' specific strengths and needs (Bouck & Long, 2023; Lemons et al., 2015). To ensure inclusive mathematics education is meaningfully implemented, it must be supported through coherent policy, legislation, and teacher training. As both a legal right and a measure of educational quality, inclusive education should be reflected in everyday classroom practice (Barr & Mavropoulou, 2019). In this context, children with DS-given their unique cognitive and genetic characteristics-deserve focused attention in both research and implementation efforts.

Developmental Characteristics Affecting the Learning of Children with DS

Cognitive Characteristics

DS is a neurogenetic condition associated with intellectual disability and is also known as trisomy 21 (Tungate & Conners, 2021). Although the degree of intellectual disability in children with DS may vary, it significantly influences their cognitive and learning processes (Grieco et al., 2015). These children often exhibit slower information processing speeds, along with widespread limitations in short-term memory, the transfer of information to long-term memory, and executive functioning (Belacchi et al., 2014; Lanfranchi et al., 2021). In addition, auditory transmission disorders and near vision impairments are frequently observed, which can particularly hinder auditory-based learning (Park et al., 2012; Yang et al., 2014). On the other hand, visual memory tends to be relatively stronger (Yang et al., 2014), making visually supported materials more effective in enhancing learning outcomes (Couzens & Cuskelly, 2014; Porter, 2022). Nevertheless, the ability to generalize learned information and transfer it to novel contexts is often limited among children with DS, which in turn negatively affects their daily living skills (Grieco et al., 2015).

Language and speech abilities are integral to cognitive development and the formation of abstract concepts. In children with DS, expressive language is typically weaker than receptive language, creating challenges in verbalizing thoughts (Grieco et al., 2015). This discrepancy restricts both social communication and academic interaction (Belacchi et al., 2014). Moreover, delays in neuromotor development may indirectly contribute to cognitive difficulties (Porter, 2022). Taken together, these factors highlight the need for greater support and the implementation of differentiated instructional strategies, particularly in cognitively demanding domains such as mathematics.

Socio-Emotional Development and Individualized Educational Approaches

Despite cognitive and physical limitations, children with DS often demonstrate notable strengths in social learning, supported by high social motivation and responsiveness to positive reinforcement-key factors in observational learning (Grieco et al., 2015). In some areas, such as emotional expressiveness, helpfulness, and empathy, they may even outperform their typically developing peers (Faragher & Clarke, 2020; Fidler et al., 2006). This pronounced social orientation facilitates their active engagement and integration in inclusive educational settings.

Aligned with evolving educational paradigms, children with DS are now more frequently raised in family environments, attend mainstream schools, and lead increasingly independent lives (Faragher & Gil-Clemente, 2019). However, variability in personality, cognition, and learning styles necessitates flexible, individualized instructional approaches (Onnivello et al., 2019). In this context, early and structured mathematics education plays a pivotal role not only in academic success but also in promoting autonomy, self-efficacy, and social inclusion.

Mathematical Development in Children with DS: Individual Differences and Learning Potential

The mathematical development of children with DS is marked by considerable variability—not only in achievement levels but also in learning styles, attention span, processing speed, and conceptual understanding (Gilligan-Lee et al., 2025; Morris et al., 2024). This heterogeneity highlights the critical need for individualized instructional approaches in mathematics education (Lanfranchi et al., 2022). For children with DS, mathematics extends beyond academic learning;

it serves as a foundation for essential functional skills such as problem-solving, planning, and decision-making in everyday contexts (Faragher & Clarke, 2020). Accordingly, Faragher and Gil-Clemente (2019) emphasize that mathematics education should not be evaluated solely in terms of attainability but should also reflect broader goals of academic and social inclusion. As Gilligan-Lee et al. (2025) point out, the development of mathematical thinking is closely tied to the ability to comprehend abstract concepts and make logical inferences-skills that are vital for fostering autonomy in daily life.

Historically, a pessimistic view prevailed regarding the mathematical potential of children with DS, often assuming pervasive deficits across all domains of mathematics (Faragher & Clarke, 2020; Sella et al., 2013). One key misconception was the generalization of difficulties with number concepts to the entire discipline (Faragher & Gil Clemente, 2019). However, the expansion of inclusive educational practices over the past two decades has begun to reshape these assumptions. Emerging evidence now demonstrates that children with DS are capable of engaging with more advanced mathematical content, including algebra, geometry, and graph interpretation (Gil-Clemente, 2019; Martinez et al., 2010). Supported by appropriate technologies, they have also shown competence in performing complex calculations. Notably, Morris et al. (2024) found no significant differences between children with DS and their typically developing peers in domains such as geometry, arithmetic, and problem-solving. These findings underscore the impact of individualized, student-centered teaching strategies and affirm the accessibility of mathematics when tailored to learners' needs (Faragher & Gil-Clemente, 2019).

Despite these advances, the majority of research on DS and mathematics remains focused on the number domain, while other areas of mathematical knowledge are relatively underexplored (Faragher & Clarke, 2020). Within this domain, children with DS exhibit marked difficulties in core skills such as number sense (Lanfranchi et al., 2021), counting (Sella et al., 2021), sequencing (Abreu-Mendoza & Arias-Trejo, 2015; Sella et al., 2013), and arithmetic (Cuskelly & Faragher, 2019). Performance in these areas often lags behind both chronological and mental age expectations (Lanfranchi et al., 2022; Sella et al., 2021). As such, a deeper and more nuanced understanding of numeracy and numerical skills is essential for advancing mathematics education for learners with DS.

Non-Symbolic Numerical Skills and Magnitude Perception

Mechanisms of Non-Symbolic Numerical Representation

To meaningfully grasp number concepts, children with DS must first develop cognitive foundations, including the ability to classify objects by attributes such as size, color, shape, and quantity (Brigstocke et al., 2008; Cowan et al., 2005). These early skills support later abilities in estimation, ordering, and measurement (Simms et al., 2020), and emerge through interaction with the environment, consistent with Vygotsky's constructivist theory (Piazza, 2010). Comparing object groups based on both quantity and perceptual features is key to developing non-symbolic and symbolic number understanding (Baroody, 2006), enabling children to move beyond memorization to meaningful mathematical reasoning (Gelman et al., 2009).

The concept of number is not limited to mathematically expressed symbols. Within the human cognitive system, two core non-symbolic numerical representation systems have been identified: the Object Tracking System (OTS) and the Approximate Number System (ANS) (Lanfranchi et al., 2021; Onnivello et al., 2019). These systems allow for an intuitive understanding of quantity independent of symbols in early childhood and are regarded as precursors to formal mathematical thinking (Siegler & Lortie-Forgues, 2014). Understanding and supporting the numerical abilities of children with DS requires a focused examination of how these systems function.

The OTS enables the rapid and accurate perception of small sets of items (typically ranging from one to four) (Sella et al., 2021). This system operates through a mechanism known as subitizing, which allows individuals to perceive the quantity of items at a glance without counting (Feigenson et al., 2004; Onnivello et al., 2019). It provides a direct sense of quantity without the need for sequencing or calculation, and as such, it forms the basis of early numerical awareness (Sella et al., 2013).

In contrast, the ANS is an evolutionarily older cognitive mechanism that enables the comparison of larger quantities (five or more) based on approximate ratios (Feigenson et al., 2004; Porter, 2022; Sella et al., 2021). Rather than evaluating exact values, the ANS operates by estimating relative differences between sets. For example, the ability to distinguish between groups with a 6:8 ratio (closer) versus a 6:12 ratio (more distinct) varies significantly (Camos, 2009). As the ratio between quantities becomes closer to 1:1, discrimination becomes more difficult—this phenomenon is referred to as the typical ratio effect (Abreu-Mendoza & Arias-Trejo, 2015). Therefore, an individual's performance

in numerical comparison tasks depends not only on absolute numerical differences but also on their sensitivity to proportional relationships (Paterson et al., 2006). For instance, distinct ratios such as 4:12 are more easily distinguished than ratios like 8:12, which are closer to unity and thus require more complex cognitive processing (Lanfranchi et al., 2021). This highlights the fact that the human brain often interprets numerical magnitudes in approximate and proportional terms rather than through precise enumeration (Feigenson et al., 2004).

Children with DS utilize non-symbolic numerical representation systems differently from typically developing children (TDC). In small-set comparison tasks relying on the OTS, they show reduced accuracy and slower responses, indicating possible limitations in OTS capacity (Sella et al., 2013, 2021). However, findings from tasks based on the ANS are more encouraging. Children with DS demonstrate age-appropriate performance when comparing larger sets (≥5 items), suggesting they can perceive ratio differences and form approximate magnitude representations (Abreu-Mendoza & Arias-Trejo, 2015; Camos, 2009). Evidence also supports the presence of the ratio effect in children with DS-a key marker of ANS functionality (Lanfranchi et al., 2021). As shown by Paterson et al. (2006), their accuracy improves with increasing ratio differences and declines as ratios narrow, mirroring typical cognitive patterns. Porter's (2022) game-based study further confirmed that ratio sensitivity affects both accuracy and response time in DS, with patterns comparable to TDC. These findings suggest that, despite symbolic number challenges, the ANS remains a relatively preserved system in children with DS.

Numerical Estimation Skills

Numerical estimation, which integrates conceptual and procedural number knowledge, is essential for understanding proportional relationships and is a strong predictor of overall math achievement (Siegler & Booth, 2015; Siegler & Opfer, 2003). The Number-to-Position (NTP) task is commonly used to assess this skill by asking children to place numbers on a number line, thereby revealing their mental representations of magnitude (Siegler & Opfer, 2003; Simms et al., 2020). Performance on the NTP task reflects whether children perceive numerical magnitudes linearly or logarithmically (Lanfranchi et al., 2022) and depends heavily on visuospatial abilities (Sella et al., 2021). Children with DS benefit from visuospatial support in such tasks, which helps reveal their intuitive grasp of quantity (Couzens & Cuskelly, 2014; de Graaf et al., 2021).

Estimation accuracy in children with DS varies by numerical range and number familiarity. In smaller ranges (e.g., 1–10), their performance closely matches that of typically developing children matched by mental age, likely due to frequent exposure to these numbers in daily life (Lanfranchi et al., 2015b, 2022). This suggests that within familiar, limited intervals, children with DS can make reliable magnitude judgments, reinforcing the functional value of estimation in both academic and everyday contexts.

When the numerical range expands-especially on a 0–100 scale-children with DS often display a logarithmic error pattern, placing smaller numbers too far from the origin and larger ones too close (Sella et al., 2021; Siegler & Opfer, 2003). This reflects a compressed mental representation of magnitude, where symbolic numbers above 20 become increasingly abstract and challenging (Siegler & Booth, 2015). Limited exposure to such numbers further impairs estimation accuracy, particularly in broader ranges (Simms et al., 2020). This pattern is attributed to both reduced familiarity with symbolic numbers and underuse of visuospatial strategies (Lanfranchi et al., 2015b, 2022). Frequent engagement with numbers and counting activities is essential for refining mental representations. Unlike typically developing children, who often rely on visual anchor points (e.g., midpoint, endpoints), children with DS struggle to use such strategies effectively, resulting in a more intuitive and less systematic approach to number line estimation (Paterson et al., 2006; de Graaf et al., 2021).

Counting Skills

Counting and Cardinality Understanding

Counting involves assigning numbers to objects in a specific sequence to determine quantity, while cardinality refers to the understanding that the final number counted represents the total number of items (Gelman et al., 2009). Unlike rote recitation, cardinality requires conceptual understanding and mental representation. Children with DS often recite number sequences without fully grasping the cardinality principle (Sarnecka & Carey, 2008; Porter, 2022; Sella et al., 2013), and early studies suggested limited conceptual number knowledge in this group (Gelman & Cohen, 1988; Cornwell, 1974, as cited in Lanfranchi et al., 2021). However, recent research challenges this view. Caycho et al. (1991) found that counting success was more strongly linked to receptive language than to the DS diagnosis itself, highlighting the importance of linguistic development. Similarly, Bashash et al. (2003) showed that while children with DS could apply the cardinality principle in short counting tasks, performance declined with longer sequences. Sella et al. (2013)

also reported that children with DS used magnitude-based strategies in number-to-dot tasks, indicating emerging conceptual understanding.

Notably, the principle of cardinality is more consistently demonstrated with short sets (3–5 items) (Bashash et al., 2003; Caycho et al., 1991; Sella et al., 2013), whereas larger sets pose challenges due to limitations in attention, memory, and processing capacity (Fidler et al., 2006; Onnivello et al., 2019). Therefore, instruction should begin with short, structured tasks to support conceptual development. Overall, counting abilities in children with DS should not be underestimated or generalized, as they are shaped by cognitive, linguistic, and instructional factors rather than by sequence memorization alone.

Cognitive Foundations of Counting Performance

Counting skills in children with DS are commonly assessed through tasks such as number recitation and object counting. Compared to TDC, children with DS often produce shorter sequences, make more frequent errors, and count at a slower pace-typically reaching only up to 20–30, with mistakes such as omissions, repetitions, or misordering (Bashash et al., 2003; Nye et al., 2001; Sella et al., 2013). These difficulties reflect the influence of underlying cognitive processes beyond numerical knowledge alone. Key contributing factors include receptive language delays, limited attention span, low motivation, and reduced working memory capacity (Fidler et al., 2006; Porter, 2022). For instance, deficits in language hinder understanding of number sequences, while weak working memory impairs tasks requiring temporary retention of numerical information. Environmental distractions and low engagement further exacerbate these challenges.

To improve counting performance, tasks must be adapted to the child's pace, supported with visual cues, and designed to maintain attention (Onnivello et al., 2019). Evaluating counting should consider not just numerical range but also the cognitive-motor strategies employed (Lanfranchi et al., 2015a). A multidimensional, individualized approach is essential for fostering both academic success and everyday numerical competence.

Arithmetic Skills in Children with DS: Cognitive and Developmental Dimensions

Developmental Dyscalculia and Its Relationship to Cognitive Profile

The arithmetic difficulties observed in children with DS tend to be more pronounced than would be expected based on their overall cognitive profiles. Cuskelly and Faragher (2019) have proposed that this discrepancy may reflect the possibility that developmental dyscalculia constitutes part of the behavioral phenotype of DS. Similarly, Brigstocke et al. (2008) reported that children with DS demonstrate relatively stronger abilities in number recognition and reading compared to their performance in arithmetic tasks. These discrepancies suggest that arithmetic competence is closely linked to cognitive components such as language development, verbal short-term memory, and number knowledge. In this context, it is believed that both fundamental cognitive limitations and patterns consistent with specific learning disorders-particularly dyscalculia-may influence how children with DS process numerical information (Cuskelly & Faragher, 2019). Therefore, the educational needs of these children must be addressed not only through strategies targeting general intellectual functioning but also through interventions specifically designed to support arithmetic-related cognitive difficulties (Porter, 2022). The findings highlighting the specificity and cognitive basis of arithmetic difficulties in children with DS underscore the importance of further investigating which cognitive processes are most implicated in these challenges.

Cognitive processes related to arithmetic skills

Arithmetic skills rely on complex cognitive processes that extend beyond basic number knowledge (Stefanelli et al., 2021). In children with Down syndrome (DS), limitations in language development and verbal short-term memory are major contributors to arithmetic difficulties (Belacchi et al., 2014; Grieco et al., 2015). Linguistic deficits hinder understanding and execution of operations, while verbal memory weaknesses disrupt the retention and manipulation of numerical information (Cuskelly & Faragher, 2019).

Deficits in verbal working memory further affect sustained attention and the orderly execution of multi-step procedures, limiting the use of arithmetic strategies (Tungate & Conners, 2021; Lanfranchi et al., 2015b). However, children with DS often demonstrate relatively stronger visuospatial abilities, which can be effectively supported through materials like Numicon, offering concrete number representations (Porter, 2022; Yang et al., 2014; Brigstocke et al., 2008).

Still, mastering number facts requires frequent repetition-something not always accessible due to limited learning opportunities. Additionally, individual differences, motivation, and learning environment quality play a significant role in arithmetic performance (Cuskelly & Faragher, 2019; Onnivello et al., 2019;). Therefore, arithmetic instruction should integrate cognitively informed strategies alongside content goals, with careful attention to task complexity and developmental variation.

Arithmetic performance in children with DS varies significantly depending not only on age but also on the difficulty level of the tasks (Brigstocke et al., 2008; Cuskelly & Faragher, 2019; Lanfranchi et al., 2015b). Lanfranchi et al. (2015b) found that school-aged children with DS performed lower than typically developing preschoolers matched on mental age. Brigstocke et al. (2008) reported that children with DS experienced difficulties both in completing basic arithmetic tests and in transferring number knowledge to computational tasks. In addition, Cuskelly and Faragher (2019) observed that arithmetic performance was particularly limited in the 20-22 age group, with difficulties becoming more pronounced as age increased. These findings suggest that arithmetic development in children with DS does not follow a linear age-related trajectory. Without the support of targeted cognitive interventions and individualized instructional strategies, arithmetic skills may fail to progress adequately over time.

Evidence-Based Recommendations for Educational Practice

Mathematical challenges in children with DS stem not only from intellectual limitations but also from cognitive and affective factors such as attention, memory, processing speed, and motivation (Fidler & Rogers, 2006; Grieco et al., 2015). Consequently, instruction should prioritize structured, interactive, and multisensory approaches tailored to individual needs.

Individualized and multisensory learning environments: Due to variability in learning pace, attention, and motivation, instruction should build on children's social strengths and preferences, incorporating visual, auditory, and tactile modalities (Grieco et al., 2015; Park et al., 2012; Yang et al., 2014). Interactive multimedia tools can further enhance engagement and learning outcomes (Porter, 2022).

Visual and multimodal instruction: Children with DS benefit from visually supported instruction, yet classroom practices often overemphasize verbal explanations (Bouck & Long, 2023; Couzens & Cuskelly, 2014). Integrating text, diagrams, graphs, and manipulatives improves comprehension and retention (Roos, 2019).

Structured play to support foundational skills: Attention, memory, and processing challenges may limit early mathematical skill development (Simms et al., 2020). Play-based activities involving sorting, sequencing, and comparison by color, shape, and size can promote conceptual understanding from an early age (Cowan et al., 2005; Porter, 2022).

Interventions targeting non-symbolic number processing: Children with DS often perform better on tasks engaging the ANS than the OTS, suggesting ANS-based learning may be more effective (Feigenson et al., 2004; Paterson et al., 2006; Sella et al., 2013). Visual materials emphasizing ratio differences can support accessibility and understanding (Abreu-Mendoza & Arias-Trejo, 2015; Lanfranchi et al., 2021).

Enhancing estimation skills with NTP tasks: Children with DS show stronger performance within limited numerical ranges. NTP tasks within the 1–20 range can bridge approximate and symbolic number understanding and serve as both instructional and diagnostic tools (de Graaf et al., 2021; Lanfranchi et al., 2022; Siegler & Lortie-Forgues, 2014).

Conceptual instructional approaches to counting and cardinality: Counting instruction should go beyond rote repetition to include an understanding of cardinality-the idea that the last number counted reflects quantity (Baroody, 2006; Sarnecka & Carey, 2008). For children with DS, multisensory techniques-like touching, listening, and visual supports-enhance engagement and understanding, especially given common language and attention challenges (Fidler et al., 2006; Onnivello et al., 2019). Using manipulatives such as cards and matching games with short number sequences is especially effective (Bashash et al., 2003; Sella et al., 2013).

Transition from non-symbolic to symbolic foundations in arithmetic skills: Since children with DS perform better in non-symbolic tasks (e.g., dot comparisons) than in symbolic arithmetic, instruction should begin with visual and estimation-based activities and gradually shift to symbolic operations (Lanfranchi et al., 2015b; Cuskelly & Faragher, 2019; Piazza, 2010).

Game-based and digital intervention programs: Game-based and digital learning tools boost attention, motivation, and skill acquisition in DS (Porter, 2022; Sella et al., 2021). Their success depends on thoughtful design-especially in terms of interface, interaction, and duration (Martin-Gutierrez & Del Rio Guerra, 2021).

Structured feedback and scaffolding approaches: Targeted feedback and scaffolding promote conceptual growth. Individualized programs like Maths For Life have shown meaningful gains in mathematical understanding for children with DS (Lemons et al., 2015; Gilligan-Lee et al., 2025).

Conclusion

This study has provided a multidimensional perspective on the mathematical learning processes of children with DS, addressing key dynamics in light of current literature and theoretical frameworks. The findings indicate that the challenges observed in the mathematical development of children with DS cannot be attributed solely to limitations in general intellectual capacity. Instead, they are closely associated with vulnerabilities in specific cognitive subsystems such as verbal memory, attention span, executive functions, and linguistic processing. Nevertheless, their strengths in areas such as visuospatial attention and pattern recognition suggest that, with appropriate instructional strategies, children with DS have the potential to achieve meaningful academic gains.

In the acquisition of fundamental mathematical skills-such as counting, cardinality, number comparison, and arithmetic operations-task type, mode of presentation, and sensitivity to difficulty level emerge as critical variables. In particular, insights gained from non-symbolic numerical processing systems (OTS and ANS) highlight the positive impact of designing instructional content aligned with these systems. NTP tasks appear to serve a dual role as both pedagogical tools and diagnostic measures that shape children's proportional magnitude representations.

Within this framework, it becomes essential to develop individualized instructional environments for children with DS, enriched with visual-auditory elements and grounded in multisensory learning principles. The use of structured feedback in tasks involving estimation, sequencing, and computation enhances both retention and conceptual clarity. Furthermore, adapting instructional materials to match students' processing speed, attention span, and motivational profiles directly influences the quality of learning outcomes.

Finally, enhancing the mathematical learning experiences of children with DS plays a key role not only in supporting individual achievement but also in the effective implementation of inclusive education policies. The integration of interdisciplinary, theoretically grounded, and practice-informed intervention models into the education system has the potential to significantly improve both the academic success and everyday independence of these learners.

Contributions of the Researchers

All authors contributed to the manuscript equally.

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Conflict of Interest

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