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From Table to Graph: Exploring Gifted Students' Difficulties in Drawing Solubility Graphs

Tablodan Grafiğe: Özel Yetenekli Öğrencilerin Çözünürlük Grafikleri Çizmedeki Zorluklarını Keşfetmek

Sayfa | 236

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Abstract. This study aims to identify the specific difficulties gifted students encounter when constructing graphs related to the concept of solubility—a skill central to scientific thinking and data interpretation. A qualitative case study design, allowing for an in-depth examination of gifted students' graph-drawing processes, was utilized. A total of 64 gifted middle school students were presented with tabulated data showing the solubility of five chemical compounds in water at various temperatures and were asked to draw corresponding solubility–temperature graphs. Students' graphs were analyzed using the Temiz and Tan (2009) graph-drawing rubric, which consists of nine qualitative criteria addressing key components of graph construction. The analysis focused on identifying patterns, recurring errors, and qualitative characteristics of students' graphing performances. The findings revealed that many gifted students struggled with key components of graph construction, particularly scaling and labeling the axes, accurately placing data points, and connecting them appropriately. Only a small percentage of students fully met all criteria, indicating that graphing difficulties persist even among high-ability learners. These results underscore the importance of explicitly teaching graphing skills, which are often overlooked in gifted education. The study contributes to the limited body of research on gifted students' graphical representational skills, specifically their ability to visually represent and organize scientific data through graphs, and provides insights for designing targeted instructional interventions to enhance their scientific process competencies.

Keywords: Gifted students, Solubility, Graph drawing, Scientific process skills, Data interpretation.

Öz. Bu çalışmanın amacı, özel yetenekli öğrencilerin, bilimsel düşünme ve veri yorumlamanın merkezinde yer alan bir beceri olan çözünürlük kavramıyla ilgili grafikler oluştururken karşılaştıkları belirli zorlukları belirlemektir. Özel yetenekli öğrencilerin grafik çizme süreçlerinin derinlemesine incelenmesine olanak tanıyan nitel bir vaka çalışması tasarımı kullanılmıştır. 64 özel yetenekli ortaokul öğrencisine, beş kimyasal bileşiğin çeşitli sıcaklıklarda sudaki çözünürlüğünü gösteren tablolaştırılmış veriler sunulmuş ve ilgili çözünürlük-sıcaklık grafiklerini çizmeleri istenmiştir. Öğrencilerin grafikleri, grafik oluşturmanın temel bileşenlerini ele alan dokuz niteliksel kriterden oluşan Temiz ve Tan (2009) grafik çizim değerlendirme ölçeği kullanılarak analiz edilmiştir. Analiz, öğrencilerin grafik performanslarının kalıplarını, tekrarlanan hatalarını ve niteliksel özelliklerini belirlemeye odaklanmıştır. Bulgular, birçok özel yetenekli öğrencinin, özellikle eksenlerin ölçeklendirilmesi ve etiketlenmesi, veri noktalarının doğru bir şekilde yerleştirilmesi ve uygun şekilde bağlanması gibi grafik oluşturmanın temel bileşenleriyle mücadele ettiğini ortaya koymuştur. Öğrencilerin sadece küçük bir yüzdesi tüm kriterleri tam olarak karşılamıştır, bu da grafik oluşturma zorluklarının özel yetenekli öğrenciler arasında bile devam ettiğini göstermektedir. Bu sonuçlar, özel yetenekliler eğitiminde genellikle göz ardı edilen grafik becerilerinin açıkça öğretilmesinin önemini vurgulamaktadır. Bu çalışma, özel yetenekli öğrencilerin grafiksel temsil becerileri, özellikle bilimsel verileri grafikler aracılığıyla görsel olarak temsil etme ve düzenleme becerileri üzerine yapılan sınırlı sayıda araştırmaya katkıda bulunmakta ve bilimsel süreç yeterliliklerini geliştirmek için hedefe yönelik öğretim müdahaleleri tasarlamak için önemli farkındalıklar sağlamaktadır.

Anahtar Kelimeler: Özel yetenekli öğrenciler, Çözünürlük, Grafik çizimi, Bilimsel süreç becerileri, Veri yorumlama.



Genişletilmiş Özet

Giriş. Bilimsel süreç becerileri, bireylerin bilimsel düşünme, problem çözme ve karar verme gibi üst düzey bilişsel yeterliklerini geliştirmelerine yardımcı olan temel becerilerdendir. Bu beceriler, bilimin doğasını anlamada ve bilimsel bilgi üretim süreçlerini kavramada önemli rol oynamaktadır. Grafik okuma, yorumlama ve çizme becerisi ise, bilimsel süreç becerileri arasında yer alan ve verilerin analiz edilmesi, yorumlanması ve sunulmasında sıkça kullanılan araçlardan biri olarak öne çıkmaktadır. Özellikle fen bilimleri derslerinde, soyut kavramların somutlaştırılması, verilerin ilişkilendirilmesi ve kavramların görselleştirilmesi amacıyla grafiklerden sıklıkla yararlanılmaktadır. Bununla birlikte, grafik çizimi öğrenciler için sadece görsel bir sunum aracı değil, aynı zamanda bilişsel bir süreçtir ve bu süreçte öğrencilerin çeşitli kavramsal ve işlemsel bilgileri bir arada kullanmaları beklenir. Ulusal ve uluslararası literatürde yapılan araştırmalar, öğrencilerin grafik çizimi sırasında pek çok zorluk yaşadıklarını ortaya koymaktadır. Öğrenciler, eksenleri doğru belirlememe, eksenleri uygun şekilde ölçekleyememe, veri noktalarını doğru yerleştiremememe, işaretli noktaları uygun çizgilerle birleştiremememe ve grafiklere başlık yazmama gibi çok sayıda hata yapmaktadır. Bu tür hatalar, öğrencilerin grafiksel okuryazarlık düzeylerinin gelişmesi için daha fazla desteklenmesi gerektiğini ortaya koymaktadır. Grafik çizimi, sadece temel kavramların görselleştirilmesi değil, aynı zamanda bilimsel verilerin doğru temsil edilmesi ve yorumlanması açısından da kritik bir beceridir.

Bu çalışmanın amacı, özel yetenekli öğrencilerin çözünürlük konusuna ilişkin grafik çiziminde karşılaştıkları güçlükleri belirlemektir. Özel yetenekli öğrenciler, genellikle yüksek düzeyde bilişsel becerilere sahip olmalarına rağmen, prosedürel bilgi gerektiren görevlerde, özellikle yapılandırılmış görevlerde, çeşitli zorluklarla karşılaşabilmektedir. Bu bağlamda, çalışmada çözünürlüğü sıcaklığa bağlı olarak artan, azalan veya sabit kalan beş farklı kimyasal bileşiğe ilişkin veriler özel yetenekli öğrencilere sunulmuş ve bu verilere dayanarak çözünürlük-sıcaklık grafiklerini çizerek grafik becerilerini göstermeleri istenmiştir.

Yöntem. Araştırma, özel yetenekli öğrencilerin grafik çizme süreçlerinin derinlemesine incelenmesine olanak tanıyan nitel bir vaka çalışması deseniyle gerçekleştirilmiştir. Katılımcılar, İstanbul il sınırında bulunan bir Bilim ve Sanat Merkezine (BİLSEM) devam eden ve gönüllü olarak araştırmaya katılan 64 özel yetenekli öğrenciden oluşmaktadır. Öğrencilere, 0–100 °C sıcaklık aralığında beş farklı bileşiğin belirli sıcaklıklardaki çözünürlük değerlerini içeren bir tablo sunulmuştur. Ardından öğrencilere milimetrik kâğıt verilmiş ve bu verilerle aynı koordinat düzleminde çözünürlük-sıcaklık grafiklerini çizmeleri istenmiştir. Öğrenciler tarafından çizilen grafikler, Temiz ve Tan (2009) tarafından geliştirilen grafik çizimi değerlendirme rubriği doğrultusunda analiz edilmiştir. Bu rubrik, grafik çizimi sürecini dokuz ölçüt üzerinden değerlendirmektedir. Bu kriterler; eksenlerin belirlenmesi, eksenlerin adlandırılması, eksenlerin ölçeklenmesi, eksenlerin bölümlere ayrılması, eksenlerde ana sayıların gösterilmesi, veri çiftlerinin doğru yerleştirilmesi, işaretli noktaların vurgulanması, işaretli noktaların uygun çizgilerle birleştirilmesi ve grafiğin adlandırılmasıdır. Her bir kriter “doğru”, “kısmen doğru”, “yanlış” ve “boş” olarak puanlanmış; bulgular frekans ve yüzde olarak raporlanmıştır.

Sonuçlar ve Tartışma. Araştırmanın bulgularına göre, öğrencilerin üç kriter dışında (ekseni belirleme %62, eksen adlandırma %55, işaretli noktaları vurgulama %55) kalan yedi kriterdeki başarı düzeyleri %3 ile %26 arasında değişmektedir. Özellikle eksenleri ölçekleme ve bölümlere ayırma gibi temel grafik çizimi becerilerinde öğrencilerin büyük bir çoğunluğunun yetersiz olduğu görülmüştür. Veri



çiftlerinin doğru yerleştirilmesi ve işaretli noktaların uygun çizgilerle birleştirilmesi kriterlerinde ise sırasıyla %45 ve %47 oranında yanlış uygulama tespit edilmiştir. Ayrıca, öğrencilerin sadece %4'ünün çizdiği grafiklere başlık eklediği belirlenmiştir. Bu durum, özel yetenekli öğrencilerin bile grafik çiziminde önemli eksiklikler yaşadığını göstermektedir. Elde edilen bulgular, grafik çizimi sürecinde yaşanan güçlüklerin genellikle birbirine bağlı olduğunu da ortaya koymuştur. Örneğin, eksenleri doğru ölçekleyemeyen öğrencilerin, veri noktalarını doğru konumlandıramadıkları ve işaretli noktaları uygun çizgilerle birleştirmekte zorlandıkları gözlemlenmiştir. Aynı zamanda, öğrencilerin büyük kısmının grafik çiziminde “doğrusal çizim eğilimi” gösterdiği, yani veriler arasında eğrisel bir ilişki olması gereken durumlarda bile noktaları düz çizgilerle birleştirmeye çalıştıkları belirlenmiştir. Bu eğilim, literatürde sıklıkla vurgulanan yanlış anlamalardan biridir (Bayazıt, 2011; Leinhardt et al., 1990). Çalışmada elde edilen çizimler, Python programlama dili kullanılarak Matplotlib ve Seaborn kütüphaneleri, R programlama dili kullanılarak ise ggplot2 paketi aracılığıyla dijital ortama aktarılmıştır. Böylece grafikler daha okunabilir ve analiz edilebilir hale getirilmiştir. Bu dijitalleştirme süreci, grafiklerin yapısal hatalarını sistematik biçimde incelemek amacıyla yapay zekâ destekli görsel analiz araçlarıyla desteklenmiştir. Bu yaklaşım, öğrencilerin yaptığı hataların türlerini ve dağılımını daha ayrıntılı biçimde belirlemeye olanak tanımıştır.

Sonuç olarak, bu çalışma özel yetenekli öğrencilerin grafik çizimi konusunda çeşitli kavramsal ve yapısal eksikliklere sahip olduğunu ortaya koymuştur. Bu durum, sadece genel öğrenci kitlesi için değil, özel yetenekli öğrenciler için de grafik okuryazarlığı konusunda daha yoğun destek sağlanması gerektiğini göstermektedir. Bilimsel süreç becerilerinin kazandırılması sürecinde, grafik çizimi gibi araçların hem manuel hem de dijital ortamlarda öğretimi teşvik edilmelidir. Öğretmen eğitim programlarında, grafik çizimiyle ilgili uygulamalı modüllere daha fazla yer verilmeli; öğretim programları ise grafik okuryazarlığını destekleyen etkinliklerle zenginleştirilmelidir. Araştırmanın bulguları, özel yetenekli öğrencilerin fen eğitimi bağlamında daha yapılandırılmış grafik çizimi deneyimlerine ihtiyaç duyduklarını göstermektedir. Gelecekte yapılacak araştırmalarda, bu öğrencilerin grafik çizim süreçlerini etkileyen bilişsel ve duyuşsal faktörlerin daha ayrıntılı incelenmesi önerilmektedir.



Introduction

An individual who has well-developed scientific process skills can actively engage in learning, acquire information more effectively, and construct knowledge in a lasting, meaningful way—free from misconceptions (Gizaw and Sota, 2023; Şen and Nakiboğlu, 2012; Tan and Temiz, 2003). From this perspective, the effectiveness of educational activities is closely tied to how successfully students develop these skills. Scientific process skills not only reflect the practices employed by scientists but also form the foundation of scientific thinking and inquiry (Biswal and Behera, 2023; Karslı, 2011; Tan and Temiz, 2003). Among these skills, categorized in various ways throughout the literature (Ayas et al., 1997; Karslı, 2011; Şen and Nakiboğlu, 2012), are the abilities to read, understand, interpret, and construct graphs.

Graphs are among the most commonly encountered visual representations in education at all levels, and even in everyday life (e.g., Shah and Hoeffner, 2002). By making abstract concepts and complex information more accessible, graphs play a vital and growing role across nearly all disciplines, particularly in mathematics and science education (Bayazıt, 2011; Das and Soylu, 2023; Ivanjek et al., 2016; Okur and Güngör Seyhan, 2025; Planinic et al., 2012; Stephens, 2024). As visual tools, they are widely used to structure learning environments and enrich educational experiences (Belçer, 2009; Bilal and Salihah, 2024; Bengtsson and Ottosson, 2006; Stephens, 2024; Şahin et al., 2007; Taşar et al., 2002; Uyanık, 2007). According to Şahin et al. (2007), visual materials such as graphs are highly effective in helping students interpret verbal information. Concepts that are difficult to describe in words—or numerical data that lack inherent meaning—can be conveyed clearly through images or graphical representations. Graphs enhance the organization, interpretation, and presentation of data (Das and Soylu, 2023; Ivanjek et al., 2016; Shah, and Hoeffner, 2002; Stephens, 2024; Taşar et al., 2002; Tomková, and Páleniková, 2024). Beyond interpretation, graph construction represents a procedural form of representational competence that requires students to translate numerical or tabular data into a coherent visual structure, integrating conceptual understanding with mathematical reasoning (Kwon, 2002; Shah and Hoeffner, 2002). In addition to offering valuable alternatives to verbal and algebraic explanations, they also support the development of students' conceptual understanding (Shah, and Hoeffner, 2002; Uyanık, 2007). Recent research has emphasized that the use of graphs in science—especially physics—offers critical support in understanding dynamic relationships such as those between force, motion, and acceleration (Yeltekin Atar and Aykutlu, 2023). Despite their instructional value, effective graph use requires not only comprehension but also the procedural ability to transform data across representations. In recent studies, particularly those focusing on middle school learners, it has been observed that students frequently associate graphs with both challenge and opportunity. Many identified difficulties in plotting axes, determining variable types, and converting tabular data into graphs, despite recognizing the usefulness of graphs in simplifying abstract concepts (Tuncer Koçal and Ormanci, 2024). Moreover, findings from large-scale international assessments such as TIMSS and PISA indicate that students worldwide struggle with interpreting complex graphical representations. Both assessments include items requiring students to interpret, compare, and extrapolate from data presented in line graphs, bar graphs, and scatterplots. Turkish students, in particular, have consistently shown weaknesses in these competencies, as reflected in TIMSS (e.g., MoNE, 2020; 2024) where performance on data and graph interpretation items remains below the



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Araştırma Makalesi / Research Paper

international average (e.g., Mullis et al, 2020). Similarly, PISA results reveal that students have difficulty understanding real-world data in graphical form, especially when tasks require multistep reasoning or linking graphs to scientific contexts (OECD, 2023; MoNE, 2023). These challenges are especially noteworthy for gifted students, who are often characterized by advanced analytical reasoning, heightened pattern recognition, and strong abstract thinking skills (e.g., Parks, 2021). Despite these cognitive strengths, research suggests that gifted learners may still experience difficulties in procedural domains—such as graph construction—when explicit instruction and structured practice are lacking (Bulut, 2021; Okur and Güngör Seyhan, 2025). This discrepancy between high-level cognitive capacity and procedural execution highlights the importance of examining graph-drawing skills specifically within gifted populations. Graphic literacy has been defined as a multidimensional competency, including interpretation, modeling, and transformation skills (Kwon, 2002; Okur and Güngör Seyhan, 2025; Shah, and Hoeffner, 2002), all of which are essential for meaningful engagement in science education and everyday life. For gifted students, these competencies are particularly critical, as they are frequently engaged in inquiry-based learning, experimental design, and project-oriented research tasks that require accurate graphical representation of data (e.g., Özgür and Yılmaz, 2017; Stanley, 2021).

Despite their recognized importance in science education and everyday life, many students face significant challenges in learning to draw and interpret graphs effectively (Bayazıt, 2011; Beichner, 1994; Beler, 2009; Bowen and Roth, 2005; Bragdon et al., 2019; Dori and Sason, 2008; Forster, 2004; Gök, 2023; Okur and Güngör Seyhan, 2025; Planinic et al., 2012; Potgiether et al., 2008; Stephens, 2024; Taşar et al., 2002; Tomková, and Páleniková, 2024; Uyanık, 2007; Bilal and Salihah, 2024). These difficulties are also reflected in performance on standardized assessments in Türkiye, particularly in multiple-choice questions involving graphical interpretation (e.g., Coştu, 2023, 2025; Coştu, 2007; Kurnaz, 2013; Okur and Güngör Seyhan, 2025). Studies comparing student performance across conceptual, algorithmic, and graphical question types consistently show the lowest achievement on graph-related items (e.g., Coştu, 2023; Coştu, 2007). It has also been reported that even university-level students struggle with basic graphing tasks such as selecting appropriate axes, labeling units, or converting tabular data into graphical formats—often defaulting to familiar types like bar and line graphs regardless of the data context (Ercan et al., 2018; Gök, 2023; Sezek, 2024; Sezek and Doymuş, 2022). Studies focusing on gifted learners also indicate that high achievement in conceptual domains does not necessarily translate into proficiency in representational or procedural tasks, such as graph drawing (Author, 2023; Bulut, 2021; Okur and Güngör Seyhan, 2025). Similarly, middle school students report persistent challenges with determining the x and y axes, labeling numerical values, and selecting appropriate graph types—indicating gaps in both procedural knowledge and representational fluency (Okur and Güngör Seyhan, 2025; Tuncer Koçal and Ormancı, 2024). In the study by Yeltekin Atar and Aykutlu (2023), it was found that high school students had only intermediate-level skills in graph reading and low performance in graph drawing, with only 1.91% of students able to correctly transform between different types of motion graphs—suggesting a disconnect between conceptual understanding and graphical representation. These challenges become more pronounced when students are unfamiliar with the graphical format or the scientific content underlying the graph. Taken together with TIMSS and PISA findings, these patterns highlight systemic challenges in students' ability to work with graphical information across grade levels.

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Within the Turkish education system, gifted students receive differentiated instruction through Science and Art Centers (BİLSEM), where curricula such as “Bilimsel Yetenekleri Fark Ettirme (BYF)” and “Özel Yetenekleri Geliştirme (ÖYG)” emphasize scientific inquiry, data analysis, and project-based learning. Graph drawing constitutes a fundamental component of these programs, particularly in experimental investigations and scientific reporting tasks where students are expected to collect data, visualize relationships, and communicate findings effectively. However, despite the central role of graphs in BİLSEM’s project-oriented modules, there is limited empirical evidence documenting how gifted students actually perform in graph construction tasks or what specific difficulties they encounter during this process.

Given the challenges frequently noted in the literature, it is crucial to identify and address the difficulties gifted students experience when reading and interpreting graphs. In this regard, the lack of sufficient data on the graphing abilities of gifted students in Türkiye provides a strong rationale for this study. Accordingly, the present study aims to explore the challenges gifted students face when drawing graphs on the topic of solubility, a subject in which graphical representations are commonly used. Although previous studies have examined graphing skills among general student populations, little attention has been paid to how gifted learners engage with such visual representations—despite their advanced cognitive potential. Gifted students are often assumed to excel in abstract reasoning and pattern recognition; however, studies (e.g., Author, 2023; Bulut, 2021; Okur and Güngör Seyhan, 2025) suggest that without structured instruction, even these learners may struggle with procedural elements such as graph construction and data visualization. This assumption was challenged by findings in Yeltekin Atar and Aykutlu (2023), where even academically strong students showed weakness in tasks requiring the transformation of motion data into correct graphs. Given that international assessments also reveal gaps in top-performing students’ graph interpretation skills, there is a clear need to examine how gifted learners navigate graph-based scientific tasks. Such findings call for deeper inquiry into the specific needs of high-ability learners in graph-based tasks. Understanding the specific challenges gifted students encounter when graphing scientific data may offer insights into how their abilities can be further supported and enriched. By focusing on the context of solubility, where temperature-dependent changes are ideal for graphical analysis, this study contributes to filling a gap in the literature and provides implications for both curriculum design and instructional practices aimed at nurturing gifted learners’ scientific process skills.

Ultimately, this research not only seeks to improve pedagogical strategies for teaching graphing in science education but also highlights the importance of differentiating instruction for gifted learners whose cognitive capacities may not always align with their procedural skills in data representation. Given that graph-related competencies are developmental and can be taught, the integration of structured tasks—such as guided graph translation, formative feedback, and real-data modeling—may improve performance and foster positive attitudes toward graphing (Tuncer Koçal and Ormancı, 2024; Yeltekin Atar and Aykutlu, 2023). The first step toward developing students’ graphing skills lies in identifying the specific difficulties they encounter in graph construction and interpretation. By revealing these challenges, this study aims to provide clearer insights into the specific areas where gifted students struggle with graph construction and, in doing so, guide the



development of targeted instructional strategies that more effectively support and enhance the advancement of graphical competencies among gifted learners.

Method

Sayfa | 243

In this study, a qualitative descriptive research design was employed. Although the study was initially framed as a qualitative case study, it primarily focuses on the analysis of students' final graph products rather than the examination of graph-drawing processes through multiple data sources. Therefore, the study is more accurately characterized as a qualitative artifact analysis. This methodological orientation and its implications are acknowledged as a limitation and discussed accordingly. This design was selected because it allows for an in-depth examination of gifted students' graph-drawing outcomes and the specific difficulties reflected in their completed graphs (Stanley, 2023). Unlike quantitative descriptive survey models, this approach emphasizes identifying patterns of errors and recurring difficulties rather than measuring variables statistically. However, since no process-based data (e.g., think-aloud protocols, interviews, or classroom observations) were collected, the findings are limited to interpretations based on students' final graphical products.

Within this qualitative framework, data collection involved presenting gifted students with the solubility values of five compounds—whose solubility in water either increases, decreases, or remains relatively stable with temperature—at specific points across the 0–100 °C range (Table 1). Gifted students' graph constructions were treated as qualitative artifacts and analyzed according to predetermined criteria to identify recurring challenges and error patterns. Afterward, the gifted students were given graph paper and asked to plot solubility–temperature graphs using the data from Table 1, all within the same coordinate system.

Table 1.
Changes in the solubility of selected substances with temperature

Compounds	0 °C	20 °C	40 °C	60 °C	80 °C	100 °C
Barium hydroxide (BaOH)	2 g	4 g	8 g	21 g	101 g	230 g
Ammonia (NH ₃)	90 g	56 g	36 g	22 g	14 g	8 g
Potassium chloride (KCl)	28 g	34 g	40 g	46 g	51 g	56 g
Potassium nitrate (KNO ₃)	14 g	32 g	61 g	106 g	167 g	245 g
Sodium chloride (NaCl)	34 g	35 g	36 g	37 g	38 g	39 g

Participants

A total of 64 gifted middle school students voluntarily participated in the study. The participants were enrolled in grades 6 to 8, with an age range of approximately 11–14 years. All students were attending a Science and Art Center (BİLSEM) located in İstanbul at the time of data collection. Participants had been enrolled in BİLSEM programs for periods ranging from 1 to 4 years, depending on the time of their identification and placement. Admission to BİLSEM is based on a multi-stage national identification process coordinated by the Turkish Ministry of National Education (MoNE), which includes standardized cognitive ability assessments and domain-specific evaluations. Only students who had successfully completed this official identification process and were actively



attending BİLSEM were included in the study. No additional selection criteria (e.g., achievement level or prior graphing experience) were applied. The study group was determined using purposeful sampling, a common strategy in qualitative research for selecting participants who possess characteristics relevant to the research focus.

Sayfa | 244 **Data collection and ethical considerations**

Data were collected during regular instructional hours in a controlled classroom setting. Students were first provided with the solubility data table (see Table 1) and were then asked to construct solubility–temperature graphs individually on graph paper. No time limit was imposed; however, most students completed the task within one class period. Prior to data collection, informed consent was obtained from students’ parents or legal guardians, and assent was obtained from the students themselves. Participation was entirely voluntary, and students were informed that their responses would be used solely for research purposes and would not affect their academic evaluation.

Ethical approval for the study was obtained from the [Yildiz Technical University / Ethics Committee for Social and Human Sciences Research], with approval granted on [02.05.2025] under approval number [2025.05]. All procedures were conducted in accordance with national and institutional ethical standards for research involving human participants.

Data analysis and reliability

The graphs created by the gifted students were analyzed using the rubric developed by Temiz and Tan (2009), which consists of nine criteria for evaluating graph construction (Table 2). Each criterion was scored as “correct,” “partially correct,” “incorrect,” or “blank.” Frequencies and percentages were calculated for each category. The initial scoring was conducted independently by two researchers (one of whom is the author of the paper) who were experienced in science education and graphical analysis. To establish inter-rater reliability, percentage agreement was calculated across all criteria, yielding an agreement rate of between 90-95%, which is considered acceptable for qualitative rubric-based analysis. Discrepancies were resolved through discussion until consensus was reached. This collaborative scoring process was implemented to minimize researcher bias and enhance the reliability of the findings.

To enhance clarity and support systematic visual analysis, students’ hand-drawn graphs were digitized. Digitization was carried out using Python (Matplotlib library) and R (ggplot2 package) to recreate each graph in a standardized digital format. Original axis scales, data points, and proportions were preserved by manually matching the numerical values and coordinates from the hand-drawn graphs to the digital environment. During digitization, no data smoothing or correction was applied; all student errors related to scaling, labeling, or point placement were intentionally retained. This process ensured fidelity to the original drawings while enabling clearer visualization and comparison across student responses. The digitized graphs supported pattern recognition and facilitated the identification of common graphical errors that were less apparent in handwritten form.



To support validity, the solubility data were derived from scientifically accepted chemical references, and the selected compounds represented distinct solubility–temperature trends. Content validity was further ensured by aligning the evaluation criteria with established literature (Temiz and Tan, 2009). However, the study has methodological limitations. Because data collection relied solely on gifted students' final graph products, it was not possible to examine the cognitive or procedural processes underlying graph construction. As such, interpretations are limited to observable outcomes rather than gifted students' reasoning strategies. This limitation should be considered when interpreting the findings and highlights the need for future studies incorporating interviews, think-aloud protocols, or classroom observations.

Results

The graphs produced by the gifted students were evaluated according to the criteria established by Temiz and Tan (2009), as detailed in Table 2, and the aggregated results are presented in the corresponding table. Although the present analysis is based on gifted students' final graph products rather than direct observations or verbal protocols, recurring error patterns in these products provide indirect yet meaningful insights into gifted students' procedural reasoning and decision-making processes during graph construction. From a product-oriented perspective, each error pattern was interpreted not only as an outcome but also as an indicator of underlying cognitive and procedural challenges, such as difficulties in variable identification, sequencing of graphing steps, and coordination between numerical data and spatial representation.

Table 2.

The levels of meeting the criteria of the solubility-temperature graphs drawn by gifted students

Criteria	Categories	f	%
Determination of horizontal and vertical axes (1)	Correct (C)	40	62
	Not correct (NC)	24	38
	Blank (B)	-	-
Nomenclature of axes (2)	Correct (C)	35	55
	Partially Correct (PC)	17	27
	Not correct (NC)	-	-
	Blank (B)	12	18
Scaling of axes (3)	Correct (C)	17	26
	Partially Correct (PC)	41	65
	Not correct (NC)	6	9
Blank (B)	Blank (B)	-	-
	Correct (C)	17	26
	Partially Correct (PC)	41	65
	Not correct (NC)	6	9
Splitting of axes (4)	Blank (B)	-	-
	Correct (C)	15	23
	Partially Correct (PC)	46	72
	Not correct (NC)	3	5
Displaying main division figures for axes (5)	Blank (B)	-	-
	Correct (C)	13	20



Correct placement of data pairs on axes (6)	Partially Correct (PC)	22	34
	Not correct (NC)	29	45
	Blank (B)	-	-
Appropriate highlighting of marked points (7)	Correct (C)	35	55
	Partially Correct (PC)	18	28
	Not correct (NC)	11	17
	Blank (B)	-	-
Connecting marked points with appropriate lines (8)	Correct (C)	13	21
	Partially Correct (PC)	20	31
	Not correct (NC)	30	47
	Blank (B)	1	1
Naming the graph (9)	Correct (C)	2	3
	Not correct (NC)	-	-
	Blank (B)	62	97

As shown in Table 2, 62% of the gifted students correctly identified the horizontal and vertical axes of the graph, while 38% did so incorrectly. Those who made errors typically placed the temperature variable on the vertical axis and the solubility variable on the horizontal axis. This mistake, exemplified in Figure 1, reflects a common misunderstanding: the independent variable, temperature, should be represented on the x-axis, not the y-axis. This recurring error suggests that some gifted students may approach graph construction procedurally—by recalling familiar graph formats—rather than conceptually reasoning about variable dependency. The misplacement of variables indicates a possible disconnect between students' conceptual understanding of scientific relationships and their application of graphing conventions during the construction process.

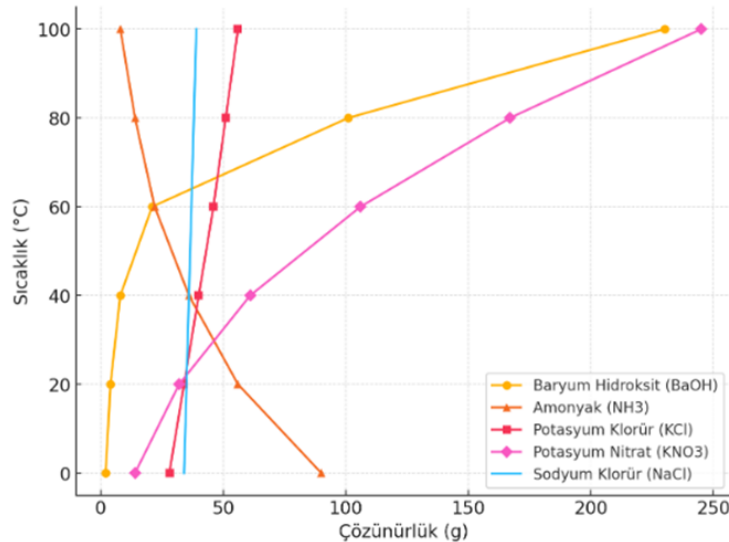


Figure 1. Drawing of a gifted student who incorrectly shows the horizontal and vertical axes

As shown in Table 2, regarding Criterion 2, 55% of the gifted students correctly labeled the axes of the graph, 27% labeled them partially correctly, and 18% did not label the axes at all. The responses of students who left both the x-axis and y-axis unlabeled were categorized as 'blank'.

Costu, F. (2026). From table to graph: Exploring gifted students' difficulties in drawing solubility graphs. *Western Anatolia Journal of Educational Sciences*, 17(1), 236-257.

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Failure to label axes, particularly when combined with correct data plotting, may indicate that some students prioritize numerical plotting over communicative clarity. This pattern suggests that graph construction is not consistently perceived as a scientific reporting tool but rather as a mechanical task focused on placing points.

Sayfa | 247

As shown in Table 2, 26% of the gifted students correctly scaled the axes, 65% partially scaled them correctly, and 9% scaled them incorrectly when drawing the graphs. As illustrated in Figure 2, the gifted students had difficulty accurately scaling either the x-axis, the y-axis, or both. Those who scaled the axes incorrectly failed to assign appropriate numerical values to the divisions on the millimeter paper, which led to errors in representing the data. Consequently, inaccuracies in scaling on the x- or y-axis resulted in graphs that did not accurately reflect the given data. These findings suggest that scaling is one of the most cognitively demanding steps in the graphing process, requiring gifted students to coordinate proportional reasoning, numerical estimation, and spatial representation simultaneously. The prevalence of partial correctness indicates that gifted students often initiated the scaling process correctly but were unable to sustain consistent proportional reasoning across the entire axis.

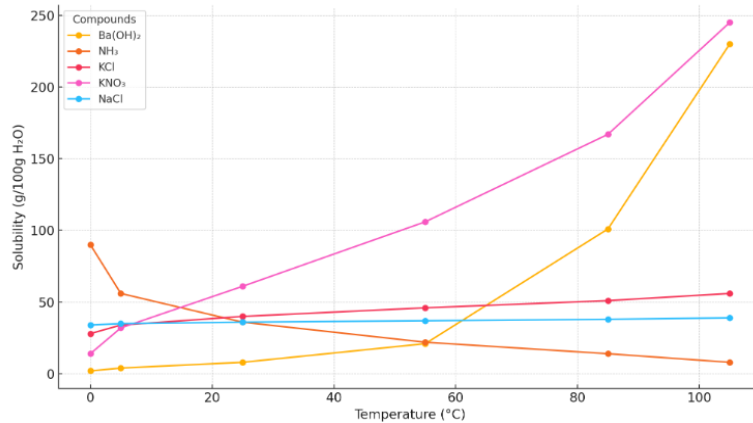


Figure 2. Graph with incorrectly scaled axes

As shown in Table 2, regarding Criterion 4, 26% of the gifted students correctly divided the axes of the graph, 65% were partially correct, and 9% were incorrect. Figure 3 presents an example of a graph in which a gifted student incorrectly divided the axes. As illustrated in the figure, the student did not begin the x-axis division from the origin point (0, y), which resulted in an inaccurate division of the x-axis. This error pattern suggests a procedural gap in understanding the functional role of the origin in Cartesian coordinate systems. Rather than serving as a meaningful reference point, the origin appears to be treated as optional or decorative by some students, reflecting fragmented procedural knowledge.

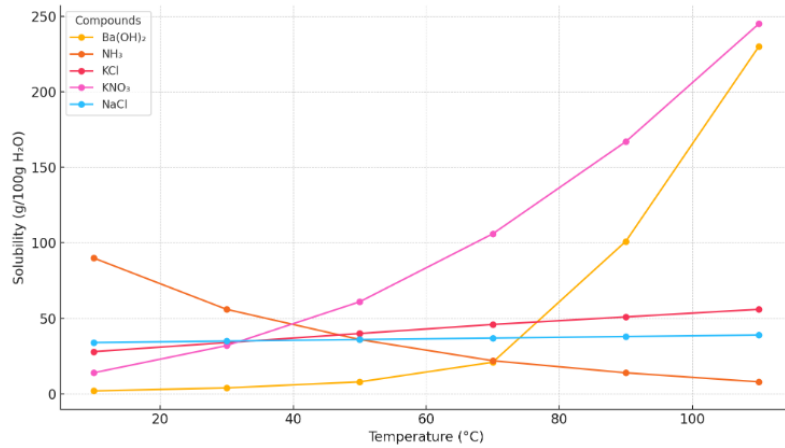


Figure 3. Graph with incorrectly divided axes

Regarding the fifth criterion, 23% of the gifted students met the criterion correctly, 72% met it partially correctly, and 5% met it incorrectly. It is noteworthy that the percentage of students who failed to meet this criterion is relatively low. However, an examination of the graphs drawn by students who partially met the criterion revealed that many used only the data values from the table, rather than applying appropriate main division intervals—particularly on the axis designated as the dependent variable. This tendency indicates that gifted students often rely on data-driven plotting without first establishing a coherent axis structure, suggesting a reversal of the recommended graphing sequence (i.e., plotting before scaling). Such procedural reversals provide indirect evidence of gifted students' reasoning paths during graph construction. As an example of this criterion, a graph drawn by one of the gifted students is shown in Figure 4.

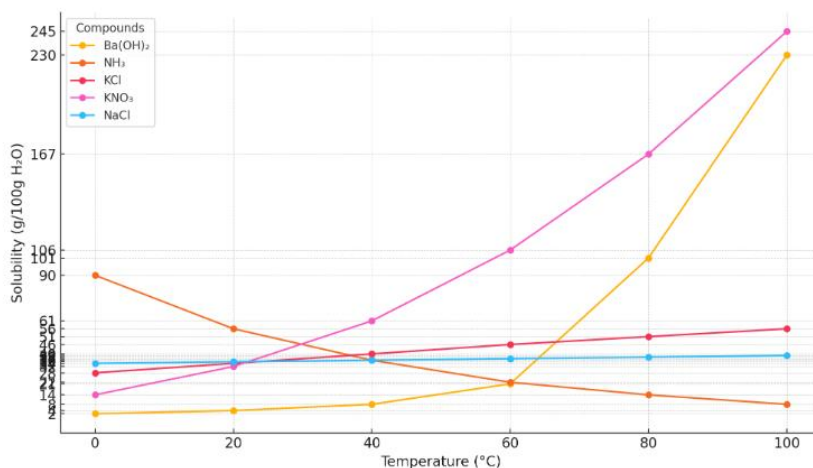


Figure 4. Graph with incorrectly labeled main divisions on the axes

Criterion 6, which involves the correct placement of data pairs on the axes, was met accurately by 20% of the gifted students, partially correctly by 34%, and incorrectly by a significant 45%. This criterion emerged as one of the most challenging for the gifted students. The difficulties



observed in this area appear to stem largely from issues with scaling the axes (Criterion 3) and dividing them appropriately (Criterion 4). The high error rate suggests that earlier procedural errors tend to propagate through subsequent steps, indicating that graph construction is a cumulative process in which initial misunderstandings significantly constrain later reasoning. This pattern highlights the importance of process awareness, even though such processes were inferred indirectly in the present study. An example of a graph drawn by a gifted student who struggled with this criterion is shown in Figure 5.

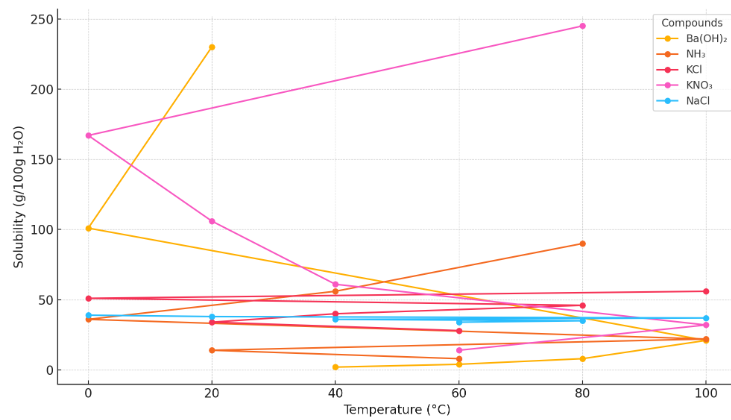


Figure 5. Illustration of a gifted student incorrectly placing data pairs on the axes

Fifty-five percent of the gifted students correctly met the criterion of making the marked points clear (i.e., Criterion 7), while 28% did so partially correctly and 17% incorrectly. Those who partially or incorrectly met this criterion were also found to have difficulty connecting the marked points with appropriate lines. This finding suggests uncertainty about whether solubility–temperature relationships should be represented as continuous or discrete, pointing to conceptual ambiguity regarding the nature of scientific data and its graphical representation. A graph drawn by one of the gifted students who made errors in fulfilling this criterion is shown in Figure 6.

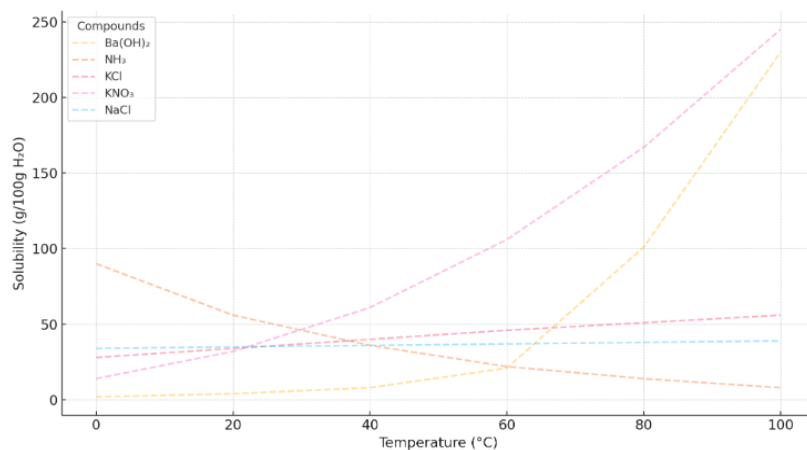


Figure 6. Graph drawn by a gifted student with incorrect highlighting of marked points



As shown in Table 2, 21% of the gifted students met the 8th criterion correctly, 31% partially correctly, and 47% incorrectly. Those who did not meet this criterion were unable to connect the data points on the x- and y-axes with appropriate lines, as illustrated in Figure 7.

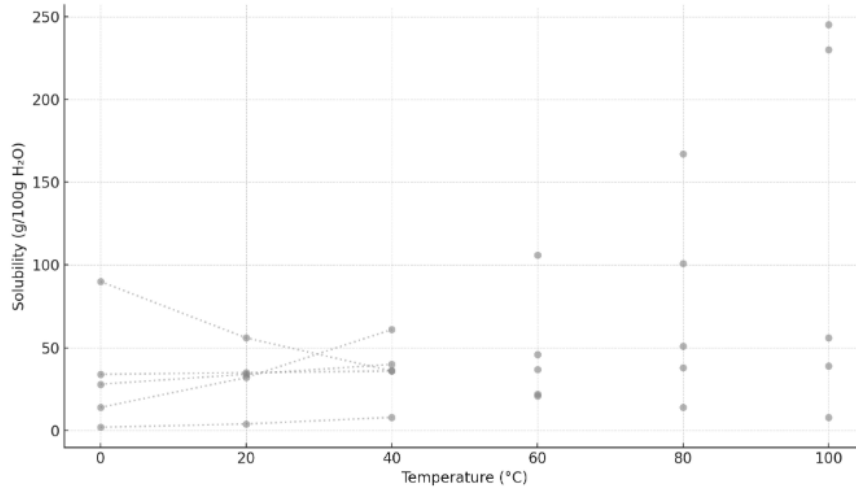


Figure 7. Graph drawn by a gifted student who failed to connect the marked points with appropriate lines

A gifted student who experienced difficulty in connecting the marked points with appropriate lines presented the data group using only distinct points, leaving the marked points unconnected in the graph (Figure 8). The omission of connecting lines may reflect a cautious reasoning strategy, where students avoid drawing relationships, they are uncertain about, or a lack of conceptual understanding that solubility changes continuously with temperature.

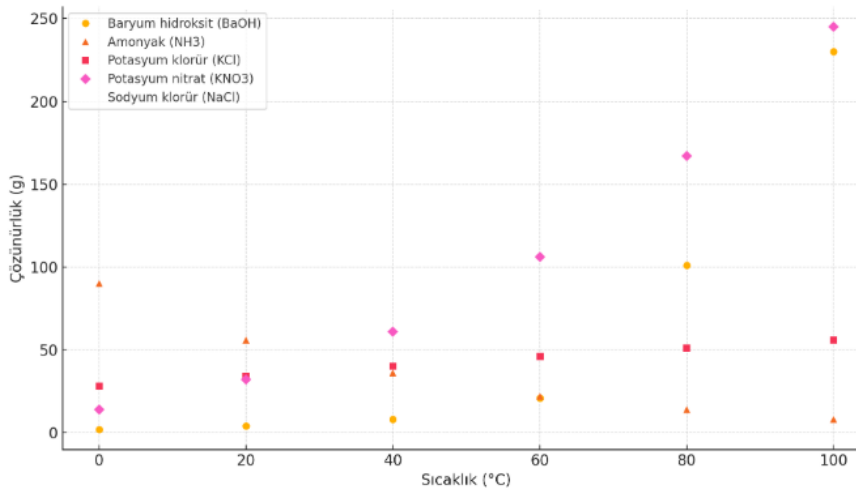


Figure 8. Graph showing marked points without appropriate connecting lines

As shown in Table 2, with respect to criterion 9, 97% of gifted students did not name the graph they drew, while only 3% did. The responses of the students who did not name the graph were Costu, F. (2026). From table to graph: Exploring gifted students' difficulties in drawing solubility graphs. *Western Anatolia Journal of Educational Sciences*, 17(1), 236-257.
DOI. 10.51460/baebd.1706226



categorized as 'blank.' The difficulties of gifted students related to the criteria listed in Table 2 are illustrated above with sample drawings. This near-universal omission suggests that students may not perceive graph naming as an integral component of scientific communication. Instead, graph construction appears to be treated primarily as a technical task rather than as a means of conveying scientific meaning to an audience. A closer examination of the graphs drawn by gifted students revealed additional challenges beyond those criteria. One such difficulty was the failure to have the axes intersect at the same point (0,0), and another was that the graph curve did not start from the origin (0,0). The issue of axes not intersecting at (0,0) was observed in graphs drawn by six gifted students, while the difficulty of starting the curve from the origin was seen in graphs drawn by two gifted students. Although no direct process data (e.g., interviews or think-aloud protocols) were collected, these observable features of student products offer indirect insights into students' procedural reasoning. Nevertheless, the absence of process-oriented data limits the depth of interpretation, and this issue is addressed as a methodological limitation in the Discussion section.

Discussion and Conclusion

The graphs drawn by the gifted students were analyzed using nine criteria. According to the analysis, the percentage of students who successfully met most of the nine criteria ranged from only 3% to 26%, except for three criteria, Criterion 1, Criterion 2, and Criterion 7, which were met correctly by 62%, 55%, and 55% of the students, respectively. These figures indicate that, overall, the gifted students did not perform as well as expected in several key areas, suggesting inadequacies in their graphing skills. This finding is particularly noteworthy given that gifted students are typically characterized by advanced analytical reasoning, high-level abstraction skills, and strong pattern-recognition abilities. However, the results of this study suggest a clear distinction between cognitive ability and procedural knowledge. While gifted learners may possess strong conceptual understanding, this does not necessarily translate into proficiency in technical or representational procedures such as graph construction. Graph drawing requires the coordinated use of multiple procedural sub-skills—scaling, partitioning, symbolization, and data transformation—which appear not to develop automatically, even among high-ability learners.

The criteria in which students showed the most difficulty included: scaling the axes, partitioning the axes, displaying the main division numbers on the axes, accurately placing data pairs on the axes, connecting marked points with appropriate lines, and naming the graph. Notably, only two students successfully fulfilled the criterion of naming the graph. These findings point to an important issue in gifted education: representational fluency—defined as the ability to generate, transform, and interpret representations—is not systematically developed unless explicitly taught. As suggested by Tairab and Khalaf Al-Naqbi (2004), one possible explanation for these shortcomings is insufficient experience and practice with manual graph drawing. In the context of BİLSEM programs, instruction often emphasizes enrichment, creativity, and project-based learning; however, explicit instruction in foundational technical skills—such as manual graph construction—may receive less systematic attention. Programs such as Bilimsel Yetenekleri Fark Ettirme (BYF) and Özel Yetenekleri Geliştirme (ÖYG) prioritize higher-order inquiry and product development, which may inadvertently assume mastery of basic procedural skills rather than explicitly teaching them. With the widespread availability of digital graphing tools, gifted students frequently rely on software-generated graphs. As Costu, F. (2026). From table to graph: Exploring gifted students' difficulties in drawing solubility graphs. *Western Anatolia Journal of Educational Sciences*, 17(1), 236-257. DOI. 10.51460/baebd.1706226



Batı Anadolu Eğitim Bilimleri Dergisi, (2026), 17 (1), 236-257.
Western Anatolia Journal of Educational Sciences, (2026), 17 (1), 236-257.
Araştırma Makalesi / Research Paper

a result, they may struggle when asked to manually construct graphs from raw data. This reliance on digital tools may weaken gifted students' understanding of scale, proportionality, and coordinate structure—core elements of procedural graphing knowledge. In addition, as shown in the study by Yeltekin Atar and Aykutlu (2023), even high-achieving students often lack confidence and fluency in drawing force–motion graphs. These findings reinforce the argument that conceptual understanding alone is insufficient for effective scientific representation; procedural fluency must be deliberately developed (Author, 2023; Coştu, 2007). This issue is especially critical for gifted students, who are frequently engaged in research projects, scientific reporting, and data presentation activities where graph construction is a core component of scientific communication.

Among the criteria that gifted students struggled to meet adequately, “scaling the axes” and “partitioning the axes” are particularly important for accurate graph construction. Failure to fully meet these criteria can result in graphs that differ significantly from the correct representations. Notably, these two criteria are structurally similar, and gifted students performed at comparable levels on both. Specifically, 26% of the students met each criterion correctly, while 65% did so partially correctly, and 9% incorrectly. These similar percentages suggest that the two criteria are closely related. The literature frequently highlights that students tend to make scaling errors on both the x- and y-axes when drawing graphs (e.g., Beler, 2009; Erbilgin et al., 2006; Gültekin, 2009; Yayla and Özsevgeç, 2015). One additional challenge resulting from these scaling and segmentation issues is the difficulty students face in correctly placing data pairs on the axes, which is another criterion many gifted students struggle to fulfill. Gifted students' performance on this criterion was also below the desired level. Specifically, 34% of the students met the criterion partially correctly, while 45% did so incorrectly. The combined percentage of these two groups (79%) is nearly equal to the combined percentage of students who partially or incorrectly met the criteria of “partitioning the axes” and “scaling the axes” (74%), which further supports this interpretation.

In addition to these four criteria, the gifted students also did not meet the criteria of “displaying the main division numbers on the axes” and “connecting the marked points with appropriate lines” at the desired level. The first of these—displaying the main division numbers—may not pose a significant issue if the x- and y-axes are already labeled with values representing data pairs. However, the second criterion—connecting the marked points with appropriate lines—is more critical. If the points are not connected accurately, the overall trend of the graph cannot be clearly determined, which may lead to significant misinterpretations. Therefore, meeting this criterion is especially important. The vast majority of gifted students (78%) met this criterion either partially correctly or incorrectly. These difficulties likely stem from not knowing how to connect the marked points. In fact, Figure 9 illustrates this well. The gifted student who drew the graph in Figure 9 correctly identified the data needed but left the graph unfinished—possibly due to uncertainty about how to connect the points. This issue may be explained by a common misconception frequently discussed in the literature: students' tendency to draw linear graphs (Bayazit, 2011; Gültekin, 2009; Leinhardt et al., 1990). Students who hold this misconception may attempt to force the points into a straight line, even when it does not accurately represent the data. A similar situation can be observed in the graph drawn by a gifted student in Figure 6. This linear bias was also observed in studies (e.g., Koçal and Ormancı, 2024), where students defaulted to straight-line connections due to a lack of understanding of curved or non-linear trends—despite the contextual data calling for them.

Costu, F. (2026). From table to graph: Exploring gifted students' difficulties in drawing solubility graphs. *Western Anatolia Journal of Educational Sciences*, 17(1), 236-257.
DOI. 10.51460/baebd.1706226



Batı Anadolu Eğitim Bilimleri Dergisi, (2026), 17 (1), 236-257.
Western Anatolia Journal of Educational Sciences, (2026), 17 (1), 236-257.
Araştırma Makalesi / Research Paper

This further supports the idea that students' procedural knowledge often lags behind their conceptual or intuitive understanding. However, gifted students' performance in meeting the criteria of “determining the horizontal and vertical axes,” “labeling the axes,” and “connecting the marked points with appropriate lines” can be considered moderate. Numerically, their success in meeting these criteria ranges from 55% to 62%. While this may seem somewhat positive, the relatively high proportion of students who met these criteria only partially or incorrectly—ranging from 38% to 45%—suggests that they still fall short of the desired level.

To summarize, when graph drawings were evaluated based on the established criteria, graphing emerged as the most challenging task for gifted students by the end of the study. The findings revealed that gifted students experienced difficulties in identifying the axes required for graph construction, scaling and partitioning the axes, correctly placing data pairs on the axes, and connecting the data points with appropriate lines. Similar challenges have been reported in international literature (e.g., Beichner, 1994; Dunham and Osborne, 1991; Parmar and Signer, 2005), which points to the broader and persistent nature of these issues across different educational contexts. These results are consistent with findings from previous studies on graphing across various disciplines and educational levels (e.g., Authors, 2018; Bayazit, 2011; Beichner, 1994; Beler, 2009; Dunham and Osborne, 1991; Erbilgin et al., 2006; Gültekin, 2009, 2014; Parmar and Signer, 2005; Tairab and Khalaf Al-Naqbi, 2004; Taşar et al., 2002; Yayla and Özsevgeç, 2015). The numerous difficulties gifted students face in graph drawing can be attributed to their lack of sufficient experience with graphing during earlier educational stages and in their current coursework. This lack of experience may also be exacerbated by technological advancements and the widespread availability of graphing software, which may have reduced the emphasis on manual graph construction (Tairab and Khalaf Al-Naqbi, 2004). As noted in the study (Yeltekin Atar and Aykutlu, 2023), even exposure to digital tools does not necessarily lead to transferable graphing skills—especially when students are not explicitly taught how to construct, scale, and interpret graphs manually. Although science curricula include learning outcomes aimed at developing scientific process skills (MoNE, 2007; 2013; 2018; 2024), it is evident that gifted students are not acquiring these skills at an adequate level. In this context, the findings of the present study carry important implications. It is believed that the results will inform future efforts to enhance the scientific process skills of gifted students and to increase their hands-on experience with graph drawing, a key component of these skills. For these instructional efforts to be effective, the starting point must be a clear identification of the specific difficulties gifted students encounter in graphical tasks. As shown in this study, these difficulties extend beyond labeling and scaling to include misconceptions about data representation and limited procedural fluency—issues that must be systematically addressed through curriculum and teacher training.

Overall, the findings demonstrate that gifted students' advanced cognitive capacities do not guarantee proficiency in technical representational skills. This mismatch highlights the need for explicit, scaffolded instruction in graph construction within gifted education settings, particularly those emphasizing scientific inquiry and research production.



Limitations of the Study

Several limitations should be considered when interpreting the findings of this study. First, the analysis relied exclusively on product-based data, namely students' final graph drawings. As a result, students' real-time reasoning processes, decision-making strategies, and moment-to-moment difficulties during graph construction could not be directly observed. Second, the study was conducted at a single BİLSEM center, which limits the generalizability of the findings to gifted students in other regions or instructional contexts. Third, the absence of process-oriented data sources—such as interviews, classroom observations, or think-aloud protocols—restricts deeper insight into the cognitive and metacognitive mechanisms underlying students' errors. Finally, although a structured rubric was used, the potential for scorer bias cannot be fully eliminated, despite efforts to ensure consistency and reliability. These limitations highlight the need for cautious interpretation and point to important directions for future research.

Implications and Recommendations

The results of the study indicated that gifted students exhibited specific and recurring challenges across multiple graphing criteria. These challenges suggest that graphing skills should not be treated as implicit or assumed competencies in gifted education. Instead:

- ✓ Manual graphing should be emphasized alongside digital tools to strengthen procedural understanding.
- ✓ BİLSEM curricula should explicitly integrate graph construction objectives within BYF, ÖYG, and project-based modules, ensuring alignment between cognitive enrichment and technical skill development.
- ✓ Teacher training programs should include instruction on diagnosing common graphing errors and supporting representational fluency.
- ✓ Structured scaffolding—from interpolation to extrapolation and from discrete data to continuous trends—should be incorporated into instruction.

Improving these areas may help gifted learners translate their cognitive potential into effective scientific representation and communication.

Recommendations for Future Research

Future studies should:

- ✓ Include larger and more diverse samples of gifted students across multiple BİLSEM centers.
- ✓ Employ longitudinal designs to examine the development of graphing skills over time.
- ✓ Use experimental or design-based research to test targeted instructional interventions.
- ✓ Incorporate qualitative process-oriented methods (e.g., interviews, think-aloud protocols, video analysis) to better understand students' reasoning during graph construction.
- ✓ Compare gifted and non-gifted populations to determine whether observed difficulties are specific to gifted learners or reflect broader instructional gaps.
- ✓ Examine the impact of digital and AI-supported tools on the transfer between manual and conceptual graphing skills.



Batı Anadolu Eğitim Bilimleri Dergisi, (2026), 17 (1), 236-257.
Western Anatolia Journal of Educational Sciences, (2026), 17 (1), 236-257.
Araştırma Makalesi / Research Paper

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