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Al-Jazari's Mechanical Devices Featuring Musical Elements: Examples That Inspire a STEAM Approach

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Abstract

This study examines mechanical devices incorporating musical elements in Kitab fī Maʿrifat al-Ḥiyal al-Handasiyya by El-Cezeri, one of the leading scientists of the 12th century, within the STEAM framework. Document analysis was employed as the research method, and criterion sampling, a purposive sampling method, was used to select the data sources. In accordance with the defined criteria, four mechanical devices that include a musical function actively integrated into their mechanical systems were selected. The data were analysed using deductive content analysis, and themes were developed related to the devices' structural characteristics, musical elements, associated STEAM disciplines, and the purposes of musical use. The findings indicate that El-Cezeri's mechanical designs are not only technically advanced but also multifunctional systems that effectively employ music for timekeeping, entertainment, and automatic operation. These devices demonstrate the integrated use of engineering, hydrodynamics, mathematics, astronomy, visual arts, and music. Notably, the mechanisms that enable musical instruments to play automatically represent early examples of programmable systems. Overall, the results suggest that the fundamental principles of the STEAM approach have existed for centuries and that art, particularly music, has historically been integrated with STEAM disciplines, highlighting the historical roots of STEAM education.

Keywords

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El-Cezeri'nin Müziksel Ögeler İçeren Mekanik Cihazları: STEAM Yaklaşımına İlham Veren Örnekler

Öz

Bu çalışma, 12. yüzyılın önde gelen bilim insanlarından El-Cezeri'nin Kitab fī Maʿrifat al-Ḥiyal al-Handasiyya adlı eserinde, müziksel unsurları içeren mekanik cihazları, STEAM yaklaşımı çerçevesinde incelemektedir. Araştırma yöntemi olarak belge analizi kullanılmış ve veri kaynaklarının seçimi için amaçlı örnekleme yöntemlerinden ölçüt örnekleme yöntemi uygulanmıştır. Tanımlanan kriterlere göre, mekanik sistemlerine aktif olarak entegre edilmiş müziksel bir fonksiyona sahip dört mekanik cihaz seçilmiştir. Veriler, tümdengelimci içerik analizi kullanılarak analiz edilmiş ve cihazların yapısal özellikleri, müziksel unsurları, ilgili STEAM disiplinleri ve müziksel kullanım amaçlarıyla ilgili temalar oluşturulmuştur. Bulgular, El-Cezeri'nin mekanik tasarımlarının sadece teknik olarak gelişmiş olmakla kalmayıp, aynı zamanda zaman tutma, eğlence ve otomatik çalışma için müziği etkili bir şekilde kullanan çok fonksiyonlu sistemler olduğunu göstermektedir. Bu cihazlar; mühendislik, hidrodinamik, matematik, astronomi, görsel sanatlar ve müziğin entegre kullanımını göstermektedir. Özellikle, müzik aletlerinin otomatik olarak çalmasını sağlayan mekanizmalar, programlanabilir sistemlerin erken örneklerini temsil etmektedir. Genel olarak, sonuçlar STEAM yaklaşımının temel ilkelerinin yüzyıllardır var olduğunu göstermektedir. Sanatın, özellikle müziğin, tarihsel olarak STEAM disiplinleriyle bütünleştiği ve STEAM eğitiminin tarihsel kökenlerini vurguladığı görülmektedir.

Anahtar Sözcükler

El-Cezeri
Mekanik
Müzik eğitimi
STEAM yaklaşımı
Tarih

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Genişletilmiş Türkçe Özet

Giriş

Bu çalışmada, 12. yüzyılın önde gelen bilim insanlarından El-Cezerî'nin "Kitab fî Maʿrifat al-Hiyal al-Handasiyya" adlı eserinde yer alan ve müziksel ögeler içeren mekanik düzenekler, STEAM yaklaşımı çerçevesinde ele alınmaktadır. Günümüzde STEAM; bilim, teknoloji, mühendislik ve matematik alanlarının sanatla bütünleştirilmesini esas alan çağdaş bir eğitim ve tasarım modeli olarak tanımlanmakta, yaratıcı düşünme, estetik duyarlılık ve problem çözme becerilerinin birlikte geliştirilmesini amaçlamaktadır (Ayvacı & Ayaydın, 2018; Rolling, 2016). Bununla birlikte, bu disiplinler arası anlayışın yalnızca modern döneme özgü olmadığı; tarihsel süreçte sanat ile bilimin pek çok örnekte birlikte ele alındığı bilinmektedir (Kaplan, 2023; Shneiderman, 2003).

El-Cezerî'nin mekanik tasarımları, bu bütünleşmenin erken ve özgün örneklerinden biri olarak değerlendirilebilir. Eserlerinde müzik, yalnızca estetik ya da eğlence amaçlı bir unsur değil; zamanın ölçülmesi, mekanik hareketlerin kontrolü ve sistemlerin eşgüdümü açısından işlevsel bir bileşen olarak kullanılmıştır (al-Jazari, 1974; Chen vd., 2018). Bu yönüyle El-Cezerî'nin müzikli mekanik düzenekleri, sanat ile mühendisliğin bütüncül bir anlayışla ele alındığı sistemler sunmaktadır.

El-Cezerî'nin çalışmaları, özellikle İslam medeniyetinin bilimsel ve kültürel mirasının Batı'ya aktarılmasından sonra son yüzyıllarda yoğun akademik ilgi görmüştür (Beyler, 2023; Kaplan, 2023; Romdhane & Zeghloul, 2009; Hassaan, 2014; Faris & Elmoselhy, 2017). Ancak mevcut literatürün büyük bölümü bu eserleri daha çok makine mühendisliği, fizik ve robotik gibi teknik alanlar çerçevesinde ele almakta; estetik, sanatsal ve kültürel boyutları ise görece geri planda kalmaktadır. Oysa "Kitab fî Maʿrifat al-Hiyal al-Handasiyya", yalnızca mekanik düzenekler değil, aynı zamanda ürün tasarımı, müzik, görsel sanatlar ve zanaat alanlarına da ilham verebilecek zengin görsel ve işitsel unsurlar içermektedir (Khorasanizadeh, 2022).

Mekanik aygıtlarında estetik görünüm ile işlevselliği birlikte gözeten El-Cezerî, Yunan müzik geleneğinden esinlenerek programlanabilir müzik çalarlar geliştirmiş ve müziği mekanik sistemlere entegre etmede yenilikçi yaklaşımlar ortaya koymuştur (Sill, 2013). Buna karşın, El-Cezerî'nin tasarımlarındaki müzikal ve sanatsal ögeler bugüne kadar yeterince sistematik biçimde incelenmemiştir. Bu nedenle mevcut çalışmanın, geçmişte sanat, bilim ve teknolojinin nasıl bütüncül bir anlayışla bir araya getirildiğini inceleyerek günümüzdeki STEAM yaklaşımı içindeki sanat boyutunun önemini yeniden ortaya koyması bakımından önemli olduğu düşünülmektedir.

Yöntem

Bu çalışmada, El-Cezeri'nin "Kitab fi Ma'rifat al-Hiyal al-Handasiyya" kitabında yer alan, disiplinlerarası bir yaklaşımla tasarlanmış ve müziksel unsurlar içeren mekanik aletleri inceleyerek, müzik bağlamında STEAM yaklaşımının değerlendirilmesi amaçlanmıştır. Bu doğrultuda, ilgili araştırmada doküman analizi yöntemi kullanılmıştır. Doküman analizi sayesinde, tarihsel olguların özelliklerini inceleyerek ve bunları belirli bir çerçeveyle ilişkilendirerek bütünsel bir çalışma elde edilebilir (Yıldırım & Şimşek, 2021).

Nitel çalışmalarda, araştırma amacına en uygun ve bilgi açısından zengin veri kaynaklarına erişmek esastır. Bu tür çalışmalar için sıklıkla amaçlı örnekleme yöntemleri kullanılır (Creswell, 2012). Amaçlı örneklemenin temel amacı, araştırma konusuyla doğrudan ilgili ve derinlemesine bilgi sağlayabilecek örnekler seçmektir (Yin, 2016). Bu çalışmada veri kaynaklarını belirlemek için amaçlı örnekleme yöntemlerinden ölçüt örnekleme yöntemi kullanılmıştır. Belirlenen ölçütler, araştırmanın odak noktasını oluşturan olguyu tüm boyutlarıyla çözümleyebilmek adına, bilgi bakımından en zengin veri kaynaklarını seçmeye yönelik oluşturulmuştur. Eserin tamamının kapsamlı bir incelemesinin ardından, çalışmaya dâhil edilecek mekanik cihazların belirlenmesinde üç temel kriter esas alınmıştır. Seçilen cihazların öncelikle doğrudan müzik üreten veya müziksel bir işlev gören bir bileşene sahip olması, cihazların çalışma ilkeleri, yapısal özellikleri ve kullanım amacına ilişkin ayrıntılı açıklamaları içermesi ve son olarak, müziksel unsurların yalnızca süsleyici birer özellik olarak değil, mekanik sistemin ayrılmaz ve işlevsel birer bileşeni olarak konumlandırılması söz konusu araçların veri kaynağı olarak seçilmesindeki nihai ölçütü oluşturmaktadır. Bu ölçütler doğrultusunda ilgili kitapta yer alan dört mekanik araç araştırmanın veri kaynağı olarak belirlenmiştir.

Bu çalışmanın veri analizi iki aşamada gerçekleştirilmiştir. Birinci aşamada, El-Cezeri'nin "Kitab fi Ma'rifat al-Hiyal al-Handasiyya" adlı eserindeki mekanik cihazlar ile ilgili literatür taraması yapılmıştır. Bu süreçte, ilgili eserin Donald R. Hill tarafından İngilizce çevirisi (al-Jazari, 1974) ile Tekeli ve arkadaşları tarafından hazırlanan Türkçe çevirisi (El-Cezerî, 2002) karşılaştırmalı olarak incelenmiştir. Çeviriler arasındaki temel terminolojik farklılıklar ve teknik terimlerin aktarımı noktasında ortaya çıkan nüanslar, eserin özgün bağlamını yakalamak adına titizlikle değerlendirilmiştir. Farklı dillerdeki bu iki çevirinin birlikte kullanımı, teknik mekanik terimlerin veya karmaşık sistem açıklamalarının yanlış yorumlanma riskini minimize ederek yöntemsel bir doğrulama sağlamıştır. Analiz sürecinde, her iki kaynakta yer alan teknik açıklamalar birbiriyle çapraz sorgulamaya tabi

tutulmuş; anlam farklılığı görülen noktalarda eserin orijinalindeki teknik mantık ve Donal R. Hill'in (al_Jazari, 1974) teknik analizleri birincil referans kabul edilerek sentezlenmiştir. Bu yaklaşım, mekanik cihazların yapısal özelliklerinin ve çalışma ilkelerinin kavramsal çerçevesinin daha bütüncül ve tutarlı bir biçimde oluşturulmasına olanak tanımıştır.

İkinci aşamada ise elde edilen bulgular doğrultusunda tümdengelimci içerik analizi yöntemi uygulanmıştır. Tümdengelimci içerik analizi, önceden belirlenmiş bir kavramsal çerçevenin veri analizi sürecini yönlendirdiği bir yaklaşımdır. Bu yöntemde veriler, araştırmanın amacı doğrultusunda önceden belirlenen temalar çerçevesinde analiz edilmektedir (Yıldırım & Şimşek, 2021). Bu çalışmada, araştırmanın alt problemlerine uygun olarak "Özellikler", "Müziksel Unsurlar", "STEAM Disiplinleri" ve "Müziğin Kullanım Amacı" temaları oluşturulmuş ve analiz süreci bu temalar doğrultusunda yürütülmüştür. Araştırmanın geçerlik ve güvenirliğini sağlamak amacıyla oluşturulan tema, kategori ve kodlar alan uzmanlarının görüşüne sunulmuştur. Uzmanlar arası kodlama uyumu, Çepni (2018) tarafından önerilen formül kullanılarak hesaplanmış ve %87,5 oranında görüş birliği elde edilmiştir. Bu oran, literatürde kabul edilen güvenirlik ölçütlerinin üzerinde olup kodlama sürecinin güvenilir olduğunu göstermektedir.

Bulgular

El-Cezerî'nin "Kitab fî Maʿrifat al-Hiyal al-Handasiyya" adlı eserinde yer alan müziksel ögeler içeren dört mekanik düzenek, özellikleri, müzikal unsurları, STEAM disiplinleriyle ilişkileri ve müziğin kullanım amaçları açısından incelenmiştir. Bulgular, bu düzeneklerin yalnızca teknik araçlar değil; aynı zamanda astronomik, kültürel, sanatsal ve bilimsel işlevler taşıyan çok yönlü sistemler olduğunu göstermektedir. Su saatleri zamanın ölçülmesi için, diğer mekanik düzenekler ise eğlence ve törensel amaçlarla tasarlanmıştır. Tüm sistemlerde modüler yapı, insan ve hayvan figürleri ile mimari ögelerin kullanılması, estetik ile mühendisliğin bütünleştiğini ortaya koymaktadır. Müziksel açıdan bakıldığında, davul, zil ve tef gibi vurmalı çalgılar; flüt ve borazan gibi üflemeli çalgılar, arp ve ud gibi telli çalgılar sistemlerin ayrılmaz bir parçasıdır. Özellikle flütün tüm düzeneklerde yer alması, müziğin merkezi rolünü göstermektedir. Bu çalgılar su gücüyle çalışan mekanizmalar aracılığıyla otomatik olarak çalınmakta ve belirli zaman aralıklarında tekrarlanan müziksel diziler oluşturmaktadır.

STEAM disiplinleri bağlamında değerlendirildiğinde, düzeneklerde hidrodinamik ve astronomi (bilim), dişliler ve iletim sistemleri (mühendislik), müzik ve görsel tasarım (sanat), otomatik figürler ve zamanlanmış hareketler (teknoloji) ile geometrik ve oransal hesaplamalar (matematik) birlikte kullanılmaktadır. Bu bütünleşme, El-Cezerî'nin tasarımlarının disiplinler arası bir anlayışla geliştirildiğini açıkça ortaya koymaktadır. Müziğin işlevi yalnızca estetik değildir; aynı zamanda zamanın bildirilmesi, mekanik hareketin başlatılması ya da durdurulması ve sosyal eğlence ile ritüellerin düzenlenmesi gibi kritik görevler üstlenmektedir. Bu yönüyle El-Cezerî'nin müzikli mekanik sistemleri, erken dönem programlanabilir ve çok işlevli makineler olarak değerlendirilebilir ve STEAM yaklaşımının tarihsel temellerini somut biçimde yansıtmaktadır.

Tartışma ve Sonuç

El-Cezerî'nin müziksel ögeler içeren mekanik düzenekleri STEAM yaklaşımı çerçevesinde değerlendirildiğinde, bu sistemlerde disiplinler arası bir anlayışın baskın olduğu görülmektedir. Bulgular, bu düzeneklerin yalnızca teknik ve mühendislik ürünleri değil; aynı zamanda sanatsal tasarım, müzikal yapı ve matematiksel modellemeyi bir araya getiren bütüncül sistemler olduğunu ortaya koymaktadır. Özellikle müziğin zamanın belirlenmesi ve mekanik hareketin tetiklenmesi gibi işlevlerde kullanılması, sanatın mühendislik süreçlerine nasıl entegre edildiğine dair önemli tarihsel ipuçları sunmaktadır (Yassi, 2017).

Bu yönüyle El-Cezerî'nin çalışmaları, STEAM yaklaşımının tarihsel kökenlerinin sanıldığından çok daha eskiye dayandığını ve sanatın bilimsel üretimin ayrılmaz bir parçası olduğunu göstermektedir. Önceki araştırmalar El-Cezerî'yi ağırlıklı olarak mühendislik ve robotik alanlarında ele alırken, bu çalışma onun sanatsal yönünü de görünür kılmaktadır. Su saatleri, müzikli otomatlar ve dans eden figürler gibi tasarımlar, onun robotik, akışkanlar mekaniği ve mekanik tasarım alanlarındaki ustalığını estetik ve müzikle birleştirdiğini göstermektedir (Bülbül & Öztürk, 2024).

Ayrıca El-Cezerî, insan biçimli müzisyenleri taklit eden otomatlar geliştirerek müzik üretimini mekanik sistemlerle bütünleştirmiş ve böylece tarihteki en erken programlanabilir müzikli makinelerden bazılarını ortaya koymuştur (Ness vd., 2011, October). Bu antropomorfik müzisyen figürleri, müziğin yalnızca ses üretimi değil, aynı zamanda hareket ve görsel anlatım yoluyla da deneyimlenmesini sağlamaktadır (Jeoung-Myoung, 2023). Bu yönüyle El-Cezerî'nin tasarımları hem bilim ve mühendislik hem de sanat tarihi açısından öncü bir nitelik taşımaktadır.

Introduction

Scientific developments evolve through the interaction of complementary disciplines and are continually reshaped in response to changing social and technological contexts. The STEAM approach exemplifies this integrative perspective by combining science, technology, engineering, mathematics, and art within contemporary educational and design frameworks (Rolling, 2016). Georgette Yakman, the founder of the STEAM approach, proposed the integration of art into STEM in 2006, emphasizing the coordination of science, technology, engineering, art, and mathematics within integrative curricula (Huang, 2020). Although STEAM is often regarded as a contemporary educational model, interdisciplinary thinking has deep historical roots, as exemplified by figures such as Leonardo da Vinci in the West and Mimar Sinan in the East, who successfully integrated aesthetics, scientific knowledge, and engineering in their works (Shneiderman, 2003; Ayvacı & Ayaydın, 2018).

Many writings from the Islamic Golden Age were translated into Latin during the Renaissance, which helped European scholars gain access to important knowledge. This translation process contributed to new discoveries and inventions in Europe (Lim & Khan, 2016). The Renaissance, spanning from the 14th to the 17th centuries (Quyash et al., 2025), marked a revival of interest in the classical knowledge and ideas of ancient Greece and Rome, leading to significant advancements in fields such as science, art, and literature (Kaplan, 2023).

Bromberg and Alfonso-Goldfarb (2016) stated that music has generally received less attention in the history of science studies. One of the main reasons for this is that although music is a field of knowledge, it has not always had a scientific status. In addition, according to the researchers, the study of music requires knowledge of a different system that makes it significantly complex. However, when we look at the history pages, we see that some scientists use music as a part of science in their studies. One of these scientists is Badi'az-Zaman Abu'l-'Izz Ismail ibn Razzaz Al-Jazari (1136–1206), who lived in the 12th century.

Al-Jazari was a prominent scholar from the Artuqid dynasty of Al-Jazira in Mesopotamia, who stood out as a scientist, inventor, mechanical engineer, craftsman, artist and mathematician. He is described as the ‘father’ of modern robotics and engineering, shaping engineering designs by combining technical components and details to create original products (Nidzom et al., 2020). With these characteristics, he went down in history as one of the leading scientists of his time. Al-Jazari played an important role in the fields of engineering and art, and his title meant ‘Chief of Operations’. He was also a pioneer of scientific and artistic creativity and left a lasting legacy in the fields of engineering and art by designing functional devices for the needs of the period (Khorasanizadeh, 2022). Al-Jazari's works left a permanent mark on the fields of engineering and mechanics and significantly influenced both the scientists of his time and the engineers who later grew up in the Islamic world and Europe (Hakimov et al., 2024).

Al-Jazari is best known for his work *Kitab fi Ma'rifat al-Hiyal al-Handasiyya*, in which he described fifty mechanical devices together with their construction and operating principles. The book provides a comprehensive and methodical account of automatic mechanisms of its time and systematically presents the technological development of mechanical devices and automation (Nadarajan, 2007). Many fundamental principles of modern automation, including the crank connecting rod mechanism, are rooted in Al-Jazari’s designs, which later influenced mechanical systems worldwide (as cited in Cârciumaru, 2023). The significance of this work is further evidenced by the numerous manuscripts preserved in museums across the world (Khorasanizadeh, 2022) and by its translations into English by Donald R. Hill in 1974 and into Turkish by the Ministry of Culture in 1990 (al-Jazari, 1974; Çırak & Yörük, 2015). Owing to its detailed illustrations and visual richness, the work has also been extensively examined by art historians (Rosenthal, 1976).

Al-Jazari's works have attracted intense academic interest in recent centuries, particularly following the transfer of the scientific and cultural heritage of Islamic civilisation to the West (Beyler, 2023; Kaplan, 2023; Romdhane & Zeghloul, 2009; Hassaan, 2014; Faris & Elmoselhy, 2017). However, most of the existing literature evaluates his works within the framework of mechanical engineering, physics, robotics, and similar technical fields; in contrast, the aesthetic, artistic, and cultural aspects are mostly overlooked. Yet, Al-Jazari's work, Kitab fî Ma‘rifat al-Hiyal al-Handasiyya, contains visual and auditory elements that can inspire not only mechanically but also in artistic fields such as product design, music, painting, calligraphy, and craftsmanship (Khorasanizadeh, 2022).

El-Jazari, who employed a rich design language that prioritized both aesthetic display and functionality in his mechanical devices, also developed programmable music players inspired by the Greek musical tradition and presented innovative approaches to integrating music into mechanical systems (Sill, 2013). Nevertheless, the musical and artistic elements in Al-Jazari's mechanical devices have not been systematically studied. This situation necessitates a comparison between the holistic understanding of the relationship between art, science, and technology in the past and the modern STEAM approach.

This study aims to demonstrate that the integration of art into the STEAM approach is not a modern pedagogical innovation but has deep historical roots, with music historically interacting with science, technology, engineering, and mathematics. Focusing on the mechanical designs of Al-Jazari, the study examines the functional and aesthetic role of music in scientific production processes and highlights historical examples in which engineering, mathematics, and technology were integrated with artistic elements such as music. In doing so, it emphasizes that interdisciplinary thinking emerged long before the modern STEAM framework and that art constituted an integral component of scientific creativity in the past.

Method

Research Design

This study aimed to evaluate the STEAM approach in the context of music by examining mechanically designed tools with musical elements found in Al-Jazari's Kitab fi Ma'rifat al-Hiyal al-Handasiyya. To achieve this aim, a document analysis method was employed. Document analysis enables the systematic examination of historical phenomena by analyzing written and visual materials within a defined analytical framework (Yıldırım & Şimşek, 2021). In qualitative research, documents such as books, academic publications, and visual materials constitute important data sources for in-depth analysis (Patton, 2015; Merriam & Tisdell, 2016; Flick, 2018). Accordingly, the mechanical devices containing musical elements in the relevant work were analyzed together with their visual representations.

Within the scope of the research, a translation-focused comparative reading process was followed for Al-Jazari's work. In this process, the English translation of Donald R. Hill's work (al-Jazari, 1974) and the Turkish translation prepared by Tekeli and colleagues (El-Cezerî, 2002) were examined comparatively. The fundamental terminological differences between the translations and the nuances arising in the transfer of technical terms were carefully evaluated in order to capture the original context of the work. The combined use of these two translations in different languages provided methodological validation by minimising the risk of misinterpretation of technical mechanical terms or complex system descriptions. During the analysis, the technical explanations in both sources were cross-examined; when differences in meaning were identified, the technical logic of the original work and Hill's technical analyses were taken as primary references and synthesised accordingly. This approach enabled the conceptual framework of the structural features and working principles of mechanical devices to be constructed more holistically and consistently.

Data Sources

In qualitative research, accessing information-rich data sources that are closely aligned with the research objective is essential for achieving an in-depth understanding of the phenomenon under investigation. Accordingly, purposive sampling methods are commonly employed to select cases that can provide detailed and relevant insights (Creswell, 2012; Yin, 2016). In this study, criterion sampling, a type of purposive sampling, was used to identify the data sources. Al-Jazari's Kitab fî Maʿrifat al-Hiyal al-Handathiyya was selected as the primary data source due to its detailed technical descriptions of mechanical devices and its inclusion of automatic mechanisms associated with musical functions.

Following a comprehensive review of the entire work, mechanical devices meeting the following criteria were included in the study:

- the presence of a component that directly produces music or serves a musical function;
- detailed explanations of the device's operating principles, structural features, and intended use;
- musical elements functioning as integral components of the mechanical system rather than as purely decorative features.

As the number of mechanical devices incorporating musical elements in the work was limited, all devices that met these criteria were included in the analysis and are presented in Table 1.

Table 1
Data Sources

Mechanical Device	Name of The Mechanical Device
M1	The castle water clock
M2	The water clock of the drummers
M3	An arbiter for drinking parties
M4	A boat which is placed on a pool during a party

As shown in Table 1, the study includes four mechanical devices with musical elements, two classified as clocks and two as vessels designed for social and entertainment contexts.

The Castle Water Clock

The castle water-clock (Figure 1) is an astronomical clock designed to display the positions of the sun and the moon in relation to the zodiacal signs. Standing approximately 3.4 metres high, it is Al-Jazari's largest and most complex astronomical clock, combining timekeeping with multiple automated functions. One of its most distinctive features is the group of five automaton musicians two pipe players, two drummers, and one cymbalist who produce music automatically through a system of mechanical levers connected to a water wheel. These figures generate sounds audible from a distance to announce specific hours, particularly the sixth, ninth, and twelfth hours (Unat, 2002).

Architecturally designed as a house-like structure, the clock incorporates upper and lower doors that open sequentially at the beginning of each hour, allowing figures to emerge and indicate the passage of time. Bird figures trigger bell sounds by releasing metal balls, while musical performances accompany key hourly intervals. The upper section of the clock visually represents astronomical movements, displaying the daily motion of the sun and the lunar phases in relation to the zodiac. Through its sophisticated automatic mechanisms, the castle water-clock integrates astronomical observation, mechanical engineering, and music into a single multifunctional system (al-Jazari, 1974).

Figure 1. The castle water clock (Türkiye National Palaces Administration Archive, 2024a)

The Water Clock of The Drummers

Figure 2 illustrates Al-Jazari's water-clock of the drummers, which features seven automaton musicians, including pipe players, cymbalists, and drummers. The clock automatically produces music at the beginning of each hour, serving both timekeeping and entertainment functions, and exemplifies Al-Jazari's ability to design multifunctional automata (Krzyzaniak, 2012). Decorated with figurative elements, the clockwork system not only generates musical sounds but also incorporates coordinated movements, creating a dynamic visual and auditory display (Ülgen, 2008). The mechanism operates through a water-powered system involving cisterns, buckets, pistons, and cables, which activate the musicians via a water wheel at regular intervals. Through this hydromechanical arrangement, the automaton produces audible musical sequences and demonstrates the application of physical principles such as fluid dynamics and shifting centres of gravity in mechanical design (al-Jazari, 1974; Ülgen, 2008).

Figure 2. The water clock of the drummers (Türkiye National Palaces Administration Archive, 2024b)

An Arbiter Drinking Parties

Figure 3 presents Al-Jazari's mechanical device known as the arbiter for drinking parties, an automatic system capable of self-regulation and responding to predetermined conditions. Distinguished from his other designs by its strong aesthetic and entertaining qualities, this device integrates music, dance, and mechanical movement into a coordinated performance (Bülbül & Öztürk, 2024). The structure comprises multiple compartments housing figurative elements, including musicians, a dancer, and a horse-and-rider figure, all arranged in a vertically layered composition.

Once assembled and placed within the gathering, the mechanism operates in a programmed cycle lasting approximately twenty minutes. During each cycle, musical performances accompany the movement of figures, culminating in the horse-and-rider selecting a participant by pointing a spear. At this point, the musical and dance sequence ceases, and a drink is ceremonially served. This process is repeated multiple times at regular intervals, demonstrating Al-Jazari's use of automated sequencing, music-driven cues, and mechanical control within a social and ritual context (al-Jazari, 1974).

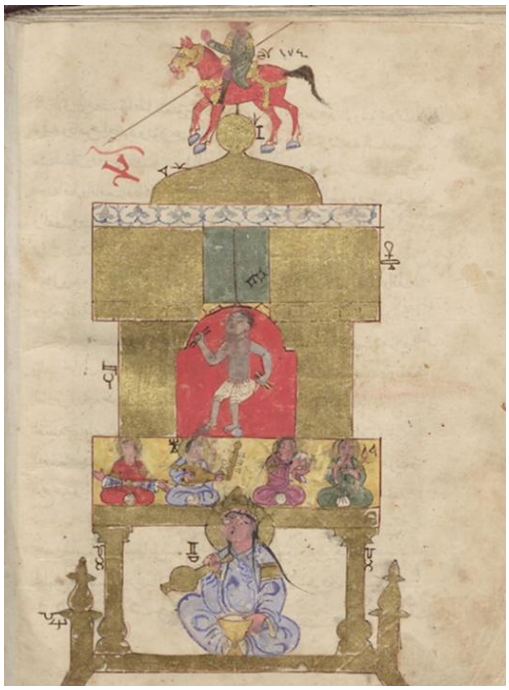

Figure 3. An arbiter for drinking parties (Türkiye National Palaces Administration Archive, 2024c)

A Boat Which is Placed on a Pool During a Party

Figure 4 illustrates another mechanical device by Al-Jazari known as the *Boat-shaped Musical Toy*, which features human-like automata performing musical and social functions on a boat floating on a pool. In this design, mechanical figures serve drinks and perform music, reflecting Al-Jazari's frequent use of anthropomorphic robots in entertainment-oriented systems (Ali & Tofiq, 2022). The boat accommodates a group of automated musicians, including tambourine players, a harpist, and a flautist, whose coordinated performances combine movement and sound within a dynamic aquatic setting (Chen et al., 2018).

The mechanism enables the boat to move continuously on the water while the musicians play in programmed sequences, with musical performances occurring at regular intervals and repeated multiple times throughout the cycle (al-Jazari, 1974). This motion is achieved through a water-powered system based on a scoop wheel, cams, rods, and followers, which activate both the propulsion of the boat and the movements of the musician figures (Chen et al., 2018). Notably, the system incorporates a programmable drum mechanism that allows different rhythmic patterns to be generated by adjusting movable pins or cams, enabling the production of varied musical sequences rather than a single repetitive rhythm. Through this design, Al-Jazari demonstrated an early form of programmable, multi-instrument musical automation driven by hydromechanical control (Dirik, 2023).

Figure 4. A boat which is placed on a pool during a party (Türkiye National Palaces Administration Archive, 2024d)

Data Analysis Method

The data analysis of this study was carried out in two stages. In the first stage, a literature review was conducted on the mechanical devices in al-Jazari's 'Kitab fi Ma'rifat al-Hiyal al-Handasiyya', and the data were analysed descriptively. In this process, the version of the relevant work translated into English by Donald R. Hill in 1974 under the title 'The Book of Knowledge of Ingenious Mechanical Devices' (al-Jazari, 1974) and the Turkish translation of the work published by the Ministry of Culture in 1990 under the title 'The Book on the Knowledge of Extraordinary Mechanical Devices' (El-Cezerî, 2002) were analysed.

In the second stage, the deductive content analysis method was applied in line with the findings obtained. Deductive content analysis is an approach in which a predetermined conceptual framework guides the content analysis process. In this method, data analysis was carried out in line with the predetermined themes in accordance with the purpose of the research (Yıldırım & Şimşek, 2021). In this study, the analysis process was carried out by creating themes titled "Characteristics", "Musical Elements", "STEAM Disciplines" and "Purpose of Using Music" in line with the sub-problems of the study.

Validity and Reliability

The themes, categories, and codes developed in this study were evaluated through expert review by four specialists. Intercoder consistency was calculated using the formula P (Consistency Percentage) = (Na × 100) / Nt (Çepni, 2018, p. 271). Two of the experts were associate professors in mathematics and science with publications on the STEM approach, while the other two held doctoral degrees in technology and music. The analysis yielded an agreement rate of 87.5%, indicating a high level of consistency between expert evaluations.

According to Tavşancıl and Aslan (2001), consistency values above 70% are considered sufficient for reliability, while Neuendorf (2002) suggests that agreement rates exceeding 80% generally indicate acceptable intercoder

reliability (as cited in Rose et al., 2015). Accordingly, the reliability of the coding process in this study can be regarded as adequate. The codes were derived directly from statements in the original source text. Based on the research questions and the deductive content analysis framework, themes and corresponding categories and codes were established and are presented in Table 2 under the themes of *Characteristics*, *Musical Elements*, *STEAM Disciplines*, and *Purpose of Using Music*.

Table 2
Themes, Categories and Codes

Theme	Category	Code
Characteristics	Purpose	Astronomical clock
		Entertainment and show
		Religious and cultural elements
	Design	Modular structure
		Use of figures
	Universality	Scientific universality
		Cultural universality
	Material and building components	Metals
		Brass sheets
		Wooden structures
		Glass structures
Musical elements	Percussion	Drum
		Cymbal
		Tambourine
	Woodwinds and brass	Trumpet
		Flute
	Strings	Harp
		Lute
STEAM disciplines	Science	Hydrodynamics
		Astronomy
	Engineering	Mechanical
		Construction
	Art	Music
		Visual arts
	Technology	Robotic
		Programming
	Math	Geometry
		Algebra
Purpose of using music		Identify the time cycle
		Mechanical trigger
		Entertainment and rituals

As given in Table 2, four main themes were identified in the research, and categories and codes were created based on these themes. Under the theme of "Characteristics", there are categories of purpose, design, universality, material and structural components. Under the theme of "Musical Elements", the categories of percussion instruments, wind instruments and stringed instruments were determined. Within the framework of the "STEAM Disciplines" theme, science, engineering, art, technology and mathematics were focused on. Finally, codes for determining the time cycle and using music as a mechanical trigger were created under the theme of "Purpose of Using Music". As a result of the content analysis, a total of 31 codes were obtained that were in line with expert opinions.

Results

In this section, four mechanical tools containing musical elements in Al-Jazari's 'Kitab fi Ma'rifat al-Hiyal al-Handasiyya' were analyzed within the framework of the determined themes. Within the scope of the research, these tools were evaluated under the headings of their characteristics, musical elements, STEAM disciplines, and the purpose of using music. The findings obtained are presented under the relevant subheadings.

Findings Presented Under the Theme of Characteristics

Table 3 shows the categories, codes and related automata created under the "characteristics theme". This theme contains 4 categories and 12 codes.

Table 3

Categories and Codes Created Under the Theme of Characteristics

Theme	Category	Code	Mechanical Devices
Characteristics	Purpose	Astronomical clock	M1, M2
		Entertainment and show	M3, M4
		Religious and cultural elements	M1, M2, M3
	Design	Modular structure	M1, M2, M3, M4
		Use of figures	M1, M2, M3, M4
		Architectural elements	M1, M2, M3
	Universality	Scientific universality	M1, M2, M3
		Cultural universality	M1, M2, M4
	Material and building components	Metals	M1, M2, M3, M4
		Brass sheets	M1, M3
		Wooden structures	M1, M2, M4
		Glass structures	M1, M2

According to the data presented in Table 3, the categories of purpose, design, universality, materials and structural components were identified under the theme of "Characteristics." The analysis indicates that the mechanical devices were designed for astronomical timekeeping, entertainment and demonstration, and religious and cultural purposes. In terms of design, a modular structure was a common feature across all devices, with figurative and architectural elements integrated into their construction. Additionally, the devices were found to possess both scientific and cultural universality. Regarding materials and structural components, metal, brass plates, and wooden structures were widely used. Overall, these findings suggest that the mechanical devices are not merely technical instruments but multifunctional systems that incorporate aesthetic, cultural, and scientific elements. Detailed explanations of the codes identified under the "Characteristics" theme are presented below.

Astronomical clock: *"A water-clock from which can be told the passage of the solar hours"* (M1). *"Being the water-clock of the drummers from which can be told the passage of the solar hours"* (M2).

Entertainment and show: *"It is taken into the drinking party in three parts"* (M3). *"It is a boat which is placed on a pool during a drinking party"* (M4).

Religious and cultural elements: *"At the side of the frieze is a crescent [moon] like a Dinar. God is all-knowing"* (M1). *"Below the centre of the frieze is a mihrab with a falcon in it, as in the first chapter, with a vase in front of it on a projecting bracket, with a cavity (in the wall behind), as (described) previously"* (M2). *"Above this castle is a dome upon which are a horse and rider"* (M3).

Modular structure*: "This is divided into 10 sections"* (M1). *"It is divided into 5 sections*" (M2). *"It is divided into five sections"* (M3). *"It is divided into three sections"* (M4).

Use of figures: *"A figure, made according to the choice of the craftsman, comes out and stands as if he had suddenly emerged"* (M1). *"The figure of a standing man is made, who has his legs on the plate and his forefinger pointing to the tip of a battlement"* (M2). *"In its front is a door with two leaves which open and close in a light kiosk (bayt) large enough for the figure of a man to stand in"* (M3). *"On the platform is the seated figure of the king, with his chamberlain (hajib) standing on his right at the back of the platform"* (M4).

Architectural elements: *"The outside consists of a house, rising from the ground a distance of about twice the height of a man, comprising all that is required for telling the passage of the hours"* (M1). *"Know then, that*

behind this chamber (Twan) is a house which is raised above the chamber and extends beneath the platform" (M2). *"Then four hollow brass columns are made each 2 sp. long"* (M3).

Scientific universality: *"The sun climbs until noon, then descends until nightfall"* (M1). *"As the vessel fills the water rises to [the bend of] the siphon, and discharges through it into a cistern by the side of the vessel"* (M2). *"Whoever wishes to construct (this) should not fit the base (plate) to the castle before the mechanisms are complete, and until they have been tested for (several) days, with several [tests] each day"* (M3).

Cultural universality: *"For mosques and shrines it may be limited to what is necessary for telling the hours; for the palaces of kings, what may be fitting, such as pictures and other things"* (M1). *"Then the slave-girl tilts the bottle until its mouth is near the rim of the goblet, and pours from the bottle clarified, blended, wine until the goblet is nearly full"* (M3). *"On its stem is a platform with a dome above it, and on the platform is the seated figure of the king, with his chamberlain (hajib) standing on his right at the back of the platform"* (M4).

Metals: *"Another is placed above it, and connected to it; outside the joint a ring of copper is fitted and firmly soldered"* (M1). *"Then an iron rod with a smooth end is fitted to the top of the cart, and its end is bent over so that it passes below the hooks and above the weights which are suspended by the rings to the hooks"* (M2). *"A dais is made with feet of cast bronze, a deck of copper and a fretted balustrade of cast bronze, all of excellent workmanship"* (M3). *"The figure of a slave-girl flautist is made from jointed copper"* (M4).

Brass sheets: *"For the flow regulator and for the water outlet one takes a strong brass plate and makes its surface flat, so that a straight-edge can be laid over it"* (M1). *"A rectangular castle is made from brass"* (M3).

Wooden structures: *"To obtain a true shape, one takes a perfectly round disc of wood, that can only with difficulty be fitted into the vessel by hammering and making adjustments"* (M1). *"Seven men are made from jointed wood"* (M2). *"It is a handsome boat made of wood, decked over"* (M4).

Glass structures: *"At the beginning of the night the first of the glass roundels will show light like a nail-paring which increases until it is filled with light, at which time an hour of the night has passed"* (M1). *"Above the frieze and parallel to it are twelve glass roundels in a straight line [set] in holes [cut] through to the inside of the house"* (M2).

Findings Presented Under the Theme of Musical Elements

Table 4 shows the categories, codes and related mechanic tools obtained under the theme of "musical elements". This theme contains 3 categories and 7 codes.

Table 4
Categories and Codes Created Under the Theme of Musical Elements

Theme	Category	Code	Mechanical Devices
Musical elements	Percussion	Drum	M1, M2, M3
		Cymbal	M1, M2
		Tambourine	M3, M4
	Woodwinds and brass	Trumpet	M1, M2
		Flute	M1, M2, M3, M4
	Strings	Harp	M4
		Lute	M3

As given in Table 4, percussion, wind and stringed instruments are used in Al-Jazari's mechanical devices with musical elements. It was determined that drums and cymbals were used among percussion, trumpet and flutes among wind instruments, and harp and lute among stringed instruments. The explanations of the codes generated under the theme of musical elements are given below.

Drum: *"In the centre of the bottom of the screen the figures of two drummers are set, each with a copper drum in front of him"* (M1). *"The middle one has two kettle-drums while the two to his left and right each has a drum slung over his shoulder, its head tilted upwards so that it can be struck by a drumstick held in the right hand"* (M2). *"The drum is made of copper and has a wire tied to either side which is slung around the neck of the slave-girl"* (M3).

Cymbal: *"Next a figure is made which holds a cymbal in his hand, and his right hand moves up and down like the drummer's hand"* (M1). *"With the cymbalists, the edge of the cymbal is held in the usual place"* (M2).

Tambourine: *"One holds a flute to her mouth, another holds a tambourine, another holds a lute, and the last has a drum slung around her neck by a strap"* (M3). *"On the stem of the boat is a platform, at the opposite end to the king, upon which are a flute-player, a harpist and then a tambourine-player"* (M4).

Trumpet: *"….the trumpet comes from another source"* (M1). *"Then two trumpeters are made [standing] close together, in the hand of each of them a trumpet of the usual design, with the end in his mouth in the normal way"* (M2).

Flute: *"…the flute plays with a loud tone which is believed to come from the two trumpeters"* (M1). *"The flute plays with a sound which is heard from a far"* (M2). *"….a flute to her mouth" (M3). "For a little while, the flute player blows the flute and the [other] slave-girls play their instruments with sounds that are heard by the assembly"* (M4).

Harp: *"The harpist is made like the others of jointed copper, and the harp is of copper with a copper frame and copper strings"* (M4).

Lute: *"The lute-player holds the neck of the lute to her thigh with her left hand"* (M3).

Findings Presented Under the Theme of STEAM Disciplines

Table 5 shows the categories, codes and related mechanic tools obtained under the theme of "STEAM disciplines". This theme contains 5 categories and 10 codes.

Table 5
Categories and Codes Created Under the Theme of STEAM Disciplines

Theme	Category	Code	Mechanical Devices
STEAM disciplines	Science	Hydrodynamics	M1, M2, M3, M4
		Astronomy	M1, M2
	Engineering	Mechanical	M1, M2, M3, M4
		Construction	M1, M2, M3
	Art	Music	M1, M2, M3, M4
		Visual arts	M1, M2, M3, M4
	Technology	Robotic	M1, M2, M3, M4
		Programming	M1, M2, M3, M4
	Math	Geometry	M1, M2, M3, M4
		Algebra	M1, M2, M3, M4

As seen in Table 5, it was determined that mechanical devices were designed within the framework of science, engineering, art, technology and mathematics disciplines. In this context, hydrodynamics and astronomy were used in science, mechanics and civil engineering in engineering, music and visual arts in art, robotics and programming in technology, and geometry and algebra in mathematics. The explanations of the codes generated under the STEAM discipline's theme are given below.

Hydrodynamics: *"The connecting pipe between the wheel's trough and the vessel is filled with water and the air in the vessel is driven out through the pipe"* (M1). *"Then an oblate float is made from copper, like a hollow turnip which floats on the surface of the water"* (M2). *"The pipe of the first trough discharges into the scoops of this wheel, and the water which falls from it flows out through the hole in its underside into [something] to be described"* (M3). *"The water is sucked down into the pipe which connects the wheel's trough to the whistle's vessel, displacing the air the vessel contains, which is expelled into the whistle's ball"* (M4).

Astronomy: *"At the beginning of the day the centre of the sun will be in the appropriate degree of the Zodiac for that day, on the eastern horizon, about to rise. "The opposite degree will be on the western horizon, about to set; whenever a degree rises its opposite will set"* (M1). *"Being the water-clock of the drummers from which can be told the passage of the solar hour"* (M2).

Mechanical: *"As the water flows out the float sinks and pulls the disc. This rotates, and the other disc pulls the Cart according to the sinking of the float, and the sickle moon moves along the front of the doors"* (M1). *"The reservoir is filled with the known quantity of water and when the tap is opened and the float descends the cart moves, and the figure with it"* (M2). *"At the left-hand end of this axle a wheel is mounted opposite the disc fixed to the end of the axle of the second scoop-wheel"* (M3). *"An axle is placed beneath his feet, fixed to his feet, - its ends move about two firm bearings in the front of the boat"* (M4).

Construction: *"In this house there is a door about 9 spans in height and 5^ spans in width, which is closed by a wall of wood or bronze"* (M1). *"Know then, that behind this chamber (Twan) is a house which is raised above the chamber and extends beneath the platform"* (M2). *"Above this balcony is a mihrab like a reception-chamber (Iwan) in which there is a [male] dancer on a ball. Above this castle is a castle which is wider than it. In its front is a door with two closed leaves"* (M3).

Music: *"This happens at the end of every hour until the sixth, at which time the drummers drum, the trumpeters blow and the cymbalist plays his cymbals for a while"* (M1). *"The flute plays with a sound which is heard from a far"* (M2). *"One holds a flute to her mouth, another holds a tambourine, another holds a lute, and the last has a drum slung around her neck by a strap"* (M3). *"Then, for a little while, the flute player blows the flute and the other play their instruments with sounds that are heard by the assembly"* (M4).

Visual arts: *"The two panels of the first of the upper doors open and a figure, made according to the choice of the craftsman, comes out and stands as if he had suddenly emerged"* (M1). *"Below the centre of the frieze is a mihrab with a falcon in it, as in the first chapter, with a vase in front of it on a projecting bracket, with a cavity [in the wall behind], as [described] previously"* (M2). *"A dais is made with feet of cast bronze, a deck of copper and a fretted balustrade of cast bronze, [all] of excellent workmanship"* (M3). *"It is a handsome boat made of wood, decked over. On its stem is a platform with a dome above it, and on the platform is the seated figure of the king, with his chamberlain standing on his right at the back of the platform"* (M4).

Robotic: *"Then two firm footings are erected under the two ends of the axle, upon which the axle turns, being parallel to the hands of the drummers and the hand of the cymbalist"* (M1). *"In it an axle is inserted the ends of which rest in the slit made at the elbow, and the hand is mounted on this [axle] - when it moves it moves up and down"* (M2). *"...of the mechanisms for the horse and rider, the dancer, and the hands of the slave-girls"* (M3). *"The right hand and forearm of the tambourine-player move about an axle whose ends are fixed in her sleeve"* (M4).

Programming: *"This happens at the end of every hour until the sixth"* (M1). *"This happens every hour as I have described"* (M2). *"This is repeated about twenty times, at intervals of about twenty minutes"* (M3). *"The flute-player blows the flute audibly and the slave-girls play the instruments, as happened the first time. They do not desist until they have performed about fifteen times"* (M4).

Geometry: *"Above the wall is a semi-circle with its convexity towards the top"* (M1). *"It is wide at the top, narrowing towards the centre, and is longer than a semi-circle, and [looks] like half a boat"* (M2). *"It is soldered firmly and then a hole of the same diameter as the pipe is made in the centre of the floor of the reservoir through to the pipe"* (M3). *"Then the end of the rod is bent at right angles in the direction of the axle"* (M4).

Algebra: *"Then the space between the two circles reserved for the 12 signs is divided into 12 equal parts"* (M1). *"Among these is a vessel [i.e. the reservoir] made as we described, its height 6 sp. and its width 1^ sp. with a tap at the bottom as before"* (M2). *"Then four hollow brass columns are made each 2 sp. long"* (M3). *"A copper reservoir, square in section, is made, with sides of 3 sp. and a height of sp."* (M4).

Findings Presented Under the Theme of Purpose of Using Music

Table 6 shows the categories, codes and related mechanical tools obtained under the theme of the purpose of using music. This theme contains 3 codes.

Table 6

Categories and Codes Created Under the Theme of Purpose of Using Music

Theme	Code	Mechanical Devices
Purpose of using music	Identify the time cycle	M1, M2
	Mechanical trigger	M2, M4
	Entertainment and rituals	M3, M4

As given in Table 6, music is used to determine the time cycle, mechanical trigger, entertainment, and rituals in mechanical devices. The explanations of the codes generated under the theme of the purpose of the use of music are given below.

Identify the time cycle: *"This happens at the end of every hour until the sixth, at which time the drummers drum, the trumpeters blow and the cymbalist plays his cymbals for a while. This occurs also at the ninth and twelfth hours"* (M1). *"This happens every hour as I have described"* (M2).

Mechanical trigger: *"The members of the band perform as long as the water falls on the scoops of the wheel. Then their movements and the sound of the trumpets cease until water discharges from the [tipping]bucket [again] when another hour has passed"* (M2). *"Then the flute-player blows the flute audibly and the slave-girls play the instruments, as happened the first time"* (M4).

Entertainment and rituals: *"The flautist plays with a sound audible to the assembly, and the slave girls play their instruments with a continuous regular rhythm, with varied sounds and drumbeats"* (M3). *"Then it emits an audible musical sound and the horse and rider rotate slowly past the members of the assembly"* (M4).

Conclusion and Discussion

In this study, Al-Jazari's mechanical devices containing musical elements were evaluated within the framework of the STEAM approach. According to the study's findings, an interdisciplinary approach was dominant in Al-Jazari's mechanical devices and music, which had both a scientific and artistic function. It was seen that mechanical devices are not only technical and engineering achievements but also holistic structures, including artistic design, musical composition and mathematical modelling.

In particular, Al-Jazari's mechanical devices with musical elements, besides reflecting the engineering skills of the period, give important clues about the use of music as a mechanical trigger and determining the time cycle. This provides an important historical reference that supports the necessity of integrating art and music into STEM disciplines in modern education systems. In addition, the fact that Al-Jazari's inventions are handled with both scientific and artistic aspects shows that engineering and art are not independent of each other but rather complementary disciplines.

The findings of this study are expected to contribute to the evaluation of Al-Jazari's mechanical devices associated with music in the context of the STEAM approach, which has not been sufficiently addressed in the literature. While Al-Jazari's contributions to the field of engineering and robotics were mainly analyzed in previous studies, his artistic aspect was also brought to the forefront in this study. In this context, it is emphasized once again that the historical roots of the STEAM approach are much older than it is believed and that art should be an inseparable part of education systems.

Al-Jazari's works demonstrate his design methodology and exceptional talent in mechanical engineering design and production areas, such as robotics, fluid mechanics, material strength and statics (Yassi, 2017). In the 13th century in Mesopotamia, Al-Jazari made innovative designs such as water clocks that combine sound, light and colour, autonomous and interactive robots that create a fun chat environment for the ruler and his guests, automata that move with dance and music and detailed these designs in his miniatures. At the same time, Al-Jazari is thought to have a universal understanding of art without considering geographical boundaries. In this respect, he predicted the art of the future by combining art with science, not only influenced the world of science in the field of art engineering but also inspired the contemporary artists of the 20th century (Bülbül & Öztürk, 2024).

One of the earliest examples of a mechanical and programmable ensemble of musical instruments was developed by al-Jazari, a scholar, inventor, artist and mathematician who lived during the Golden Age of Islam (Middle Ages in the West) (Ness et al., 2011, October). Al-Jazari also tried to realise music-playing movements by imitating anthropomorphized musicians in his mechanical instruments containing music (Jeoung-Myoung, 2023).

The results of the study indicate that the automata designed by Al-Jazari reflect a strong interdisciplinary approach in which engineering and scientific knowledge are integrated with artistic elements. This finding demonstrates that the fundamental principles of the STEAM approach were already present in historical contexts. Al-Jazari's designs reveal that technological innovation has long involved the interaction of science, engineering, and art.

Another important result of the study is the functional use of music within mechanical systems. Music in Al-Jazari's automata was not limited to an aesthetic or decorative role; rather, it functioned as a mechanical trigger and played an active role in timekeeping, entertainment, and the operation of the mechanisms. This multifunctional use highlights the scientific and mechanical significance of musical elements in early automated systems.

The findings also suggest that Al-Jazari's inventions can serve as valuable historical examples for contemporary STEAM education. His works provide a strong historical foundation for understanding the integration of art into STEM fields and demonstrate how artistic components can enhance scientific and technological development. From this perspective, Al-Jazari's automata illustrate the intertwined nature of art, science, and technology, emphasizing the importance of adopting a historical perspective in the development of modern STEAM education models.

Based on these findings, historical examples reflecting interdisciplinary approaches, such as the works of Al-Jazari, can be incorporated into STEAM educational programs to help students better understand the relationship between art and science. Furthermore, topics related to the use of music and sound in mechanical systems can be

explored in depth within current research areas such as artificial intelligence, robotics, and automation. In this context, Al-Jazari's automata are considered significant for providing important insights into the functional use of music in technological systems.

In addition, universities and research centres can be encouraged to develop interdisciplinary projects that bring together art and engineering disciplines, using Al-Jazari's works as a source of inspiration. Finally, strengthening the cultural and historical dimensions of STEAM education by including scientific and artistic contributions from different civilisations may enable students to gain a broader and more inclusive perspective on the development of science and art.

Declaration of Competing Interest

The author declares that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics Committee Permission Information: Ethics committee approval was not required for this research, as it involved only the analysis of existing documents and historical materials and did not include any form of participant-based data collection.

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