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Content analysis of music education studies related to augmented reality technology

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Highlights

- Augmented reality used in music education studies scanned Wos and Scopus from 2006 to 2020 was examined.
- The studies utilizing AR technology were primarily focused on instrument education, in particular, piano and guitar training for beginner students.
- It was concluded that AR applications used in music education accelerated learning, enabled to be more effective and enjoyable than traditional methods.

Article Info: Research Article

Keywords: *Music Education, Instrument Education, Augmented Reality, Education 4.0*

Abstract

This study aims to examine the studies scanned in Web of Science and Scopus databases between 2006-2020 on the use of augmented reality applications in music education in terms of their descriptive features, methodological features, and outcomes, and to reveal the trends in this field. The criterion sample approach was utilized in this qualitative study, and 35 selected studies were reviewed using the publication classification form and analyzed using the content analysis method. The descriptive and methodological feature data were translated into frequency values using the SPSS 22 program and then interpreted using tables and charts for easy comprehension. Furthermore, the advantages and limitations of AR applications utilized in music education, which were the research's outputs, were coded, organized into relevant categories, and interpreted. The results showed that most studies focused on piano and guitar education for beginners; no studies were undertaken on wind instruments or voice training. Studies, particularly in recent years, have focused on user experience research. Furthermore, it was found that AR applications have the advantages of increasing and facilitating student learning performance, making learning exciting and fun, and providing motivation. Some challenges during use, owing to technical issues and limited field content in the programs, resulted in limited improvements in music education.

1. Introduction

The long-practiced rote-learning-based education system has evolved into one that aspires to educate individuals who think, reason, question, create, and experience in today's fast-paced technological environment. This new education system, Education 4.0, is integrated with Industry 4.0, which is an industrial revolution that enabled human-object interaction in the twenty-first century using cutting-edge technologies such as the Internet of Things (IoT), artificial intelligence, augmented reality, and virtual reality (Doğan & Baloğlu, 2020; Görçün, 2017). In this regard, it can be understood that "Education 4.0," which means the realization of digital transformation in education, is an innovation-based process in which teaching methods and techniques are integrated with technological developments and visualized educational teaching tools are extensively used (Öztemel, 2018). This education system, which allows personalized education, is aimed at cultivating innovative generations who can keep up with technological

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developments and use them as educational materials, learn creatively and based on exploration, and make this knowledge permanent. These new technologies that have emerged in recent years and are starting to be used in education have an impact on the comprehension of knowledge, the ability to experience comprehended knowledge, and the permanence of learning, as they are based on visual and auditory learning. "Augmented reality (AR)," which consists of a combination of real-world and 3D images in the virtual world, is one of these new technologies that have become incorporated into the daily lives of the new generation via mobile devices and computers.

AR technology is used in many fields, including the military, medicine, engineering, architecture, tourism, and trade (Abdüsselam, 2016; Billinghurst et al., 2015; Somyürek, 2014) due to its attractive features, including visual richness (İçten & Bal, 2017a), 3D content, the ability to make abstract concepts concrete (Abdüsselam, 2014; Wojciechowski & Cellary, 2013), and the ability to safely teach potentially dangerous situations through simulation (Wojciechowski & Cellary, 2013). In addition to these fields, a great number of significant studies indicate that AR applications are also used in educational fields such as natural sciences (biology, physics, chemistry), mathematics, language teaching, geography, history, and art, particularly in recent years (Abdüsselam, 2014; Bacca et al., 2014; Bower et al., 2014; Challenor & Ma, 2019; Cheng & Tsai, 2013; Chitaniuc & Iftene, 2018; Erbaş & Atherton, 2020; Redondo et al., 2020; Saidin et al., 2015; Sırakaya & Alsancak Sırakaya, 2018; Yılmaz & Göktaş, 2018). Through AR technology, students can concretely explore objects as they interact with real and virtual environments. This enables them to learn complex concepts easily and improve their skills (Kirner et al., 2012).

Educational research studies have shown that AR applications can increase students' success and motivation (Bacca et al., 2014; Chiang, Yang, & Hwang, 2014; Di Serio et al., 2013; Holley, Hobbs, & Menown, 2016), encourage collaborative learning (Ke & Hsu, 2015; Martín-Gutiérrez et al., 2015), and increase students' interest (Somyürek, 2014; Tomi & Rambli, 2013). Due to these advantages, AR technology, which has become widespread in the educational fields mentioned above, has also been introduced in music education, and related studies have been increasing. Upon reviewing the literature, it is seen that some of the studies using AR technology in the field of music are related to the development of applications for fun and game-based learning (Herrero et al., 2015; Zhou et al., 2004) and instrument design (Chouvatut & Jindaluang, 2013; Zhaparov & Assanov, 2014). However, throughout the last decade, research using this new technology has been linked to the theoretical and instrumental components of music education. As a result, the AR applications investigated in this work are related to the educational use of music.

This study consists of eight sections and is structured as follows: Section II describes the literature related to the theoretical framework of AR technology and its properties. Section III reveals related studies and the gap in the field. Section IV consists of the purpose of the study and presents the research questions. Section V describes the methodology, including the research design, research sample, data collection, data analysis, and validity and reliability. Section VI presents the results, discusses the findings concerning the literature, Section VII consists of conclusions and finally, Section VIII presents suggestions and future work.

2. What is Augmented Reality?

Zhou, Duh & Billinghurst (2008) define Augmented Reality (AR) as “a technology which allows computer-generated virtual imagery to exactly overlay physical objects in real-time” (p.193). According to (Azuma (1997), an augmented reality pioneer who performed early work in this area (URL-1), the significant features of AR include the combination of virtual objects in the real world and real-time interaction with 3D objects. Computer-generated images are mixed with real-world images and displayed on mobile devices (smartphones and tablets), desktops or laptops, or head-mounted displays (HMDs) as if they were part of the same scene.

It is essential to distinguish between augmented and virtual reality concepts, which are the newest technologies of today's world and are frequently mentioned. While virtual reality is a computer-simulated virtual environment that entirely separates the user from the real world and provides them with a three-dimensional, interactive, and truly immersive experience (Scales, 2018; Somyürek, 2014), augmented reality complements and enriches the existing reality by adding computer-generated virtual factors to a real environment (Azuma, 1997; Ma & Choi, 2007). Milgram, Takemura, Utsumi & Kishino (1995) explained the concept of mixed reality (MR), which includes the combination of real and virtual environments, using the reality-virtuality continuum (see Figure 1) to better understand these two concepts. Accordingly, mixed reality can be located at any point on this continuum and combines real-world and virtual-world objects and brings them together on the same screen. Thus, it involves both augmented reality and augmented virtuality (Cheng & Tsai, 2013; Milgram & Kishino, 1994). In brief, mixed reality consists of augmented reality and augmented virtuality (Craig, 2013).

The real and virtual environments are placed at opposite ends of the reality-virtuality continuum, and it can be seen that augmented reality (AR) is close to the real environment, while augmented virtuality (AV) is close to the virtual environment (Milgram & Kishino, 1994). This can be described by adding virtual objects to a real-world environment in AR and enriching a virtual environment in AV through interaction with real-world elements. In terms of the reality-virtuality continuum, augmented reality can be defined as a sort of mixed reality in which the contents of the real and virtual environments can interact with one another (Bower, Howe, McCredie, Robinson & Grover, 2014; Hughes & Stapleton, 2005).

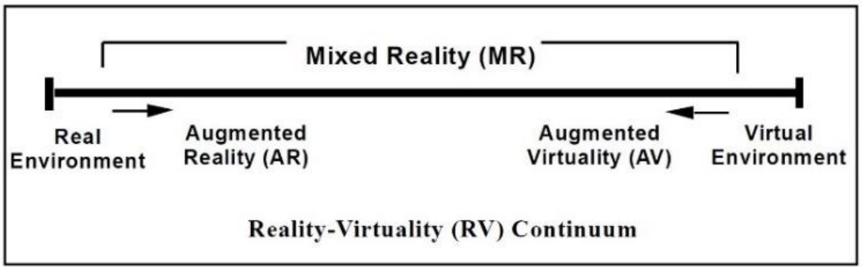

Fig. 1. Reality-Virtuality (RV) continuum (Milgram et al., 1995, p. 283)

2.1. History of Augmented Reality

Upon reviewing the literature, it can be seen that the first steps toward augmented reality technology were taken with the "Sensorama" simulator (which had 3D screens and could produce wind, smell, and vibrations) developed by Morton Heilig in the 1950s, which is considered the first study in the creation of a virtual reality system (Akbaş & Güngör, 2017; Yuen et al., 2011). The "Sword of Damocles," developed by Ivan Sutherland (a professor at Harvard University) in 1968, is considered the first AR prototype and the first head-mounted display (URL-2). Wearable devices developed by Steve Mann in the 1980s began to influence the future of AR (Mann, 1997; URL-2). In the early 1990s, scientists Thomas Caudell and David Mizell, who were involved in a project at the aircraft manufacturer Boeing, developed an AR application that showed the assembly of cables and introduced the term "augmented reality" to the field for the first time. In the mid-1990s, research on the essential technologies for AR (e.g., tracking, visualization, and interaction) accelerated, and various application areas were explored (Billinghurst et al., 2015; Caudell & Mizell, 1992; Cheng & Tsai, 2013). In 1999, Hirokazu Kato developed ARToolkit, a tracking library that follows the user's viewpoint and enables interaction with real objects, which was released as open source in 2000. This library became the most widely used application to enable people to develop AR applications (Billinghurst et al., 2015; URL-3). In 2000, the first outdoor AR mobile game, "ARQuake," was developed. Thus, AR technology began to be used in the gaming industry, and in 2016, the popular AR game "Pokemon Go" was released worldwide (URL-2). In 2009, Mistry et al. developed a new wearable AR project called "Sixth Sense," which enhances the real world with digital information and allows users to interact with it using hand gestures. This system, connected to a mobile device, allows the user to project digital information onto any surface (e.g., table, wall) and manipulate it using hand gestures like a touchscreen device, such as zooming in and out, rotating, and panning. The system could detect symbols drawn in the air by the user's hand and launch the corresponding application. For instance, if the user drew the @ symbol in the air, the system would open the mailbox (Mistry et al., 2009; URL-4). In the same year, AR became more widely recognized than virtual reality due to its availability through web browsers for the first time, the emergence of smartphone-based applications, and its use in commercial fields, which was a milestone for AR technology (Billinghurst et al., 2015). In 2012, AR glasses called "Google Glass," which could connect to smartphones via Bluetooth or WiFi were released on the market. These AR glasses, which had a touchpad on the side and could be controlled by voice commands, had certain features that could be done with a phone, such as taking photos, making video calls, playing videos, and working with the Google search engine. However, the glasses failed to meet expectations and were unsuccessful due to their privacy and security vulnerabilities and the potential for harm to eye health (Altınpulluk & Kesim, 2015; URL-5). In 2016, Microsoft introduced the "Hololens," a project that Alex Kipman had worked on for many years. Hololens, a type of AR smart glasses that provide a mixed reality experience, is described as the technology of the future. Unlike Google Glass, it enables users to perform a variety of tasks and gain a variety of experiences through holograms by combining the physical and digital worlds (people, places, and objects) into one, enabling seamless interaction between humans and computers (Altınpulluk & Kesim, 2015; Poetker, 2019; Tripathi et al., 2017). Hololens, which brought a new dimension to AR technology and was the first version of the product, was further developed in 2019 and released as Hololens 2 (URL-2), which is still in use. Work on the latest version, Hololens 3, is ongoing (URL-6).

As AR technology becomes more popular, several software development kits (SDKs) that make it easier to design augmented reality apps are being developed. AR is becoming more widespread in our daily lives through mobile and social media applications such as Snapchat (e.g., Facebook and Instagram). The timeline in Figure 2 depicts a history of the significant changes in AR technology mentioned above.

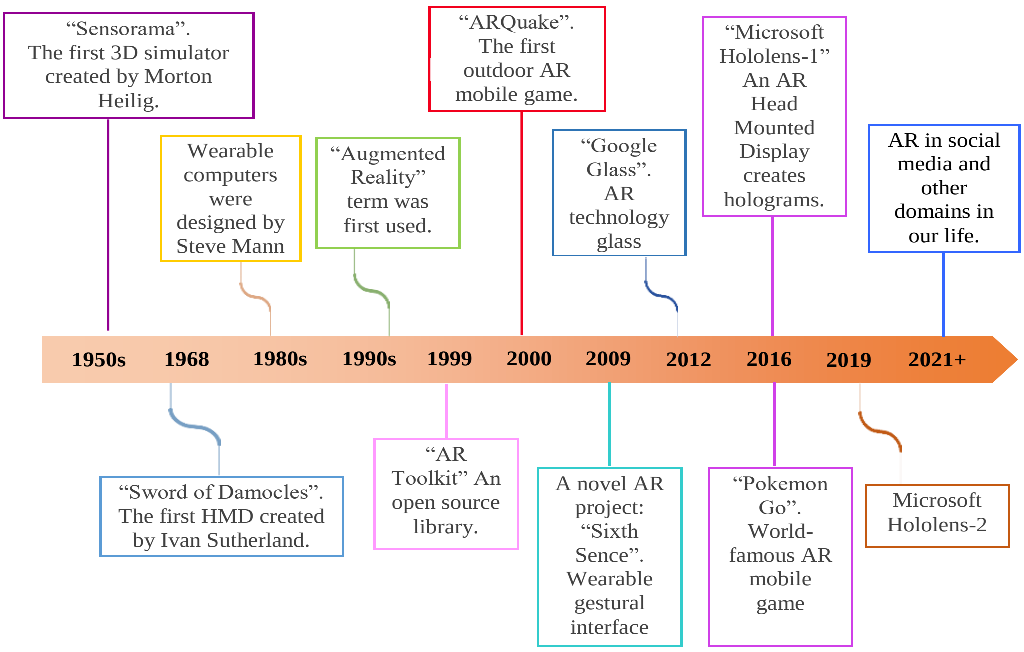

Fig. 2. History of AR

2.2. Components of Augmented Reality

AR technology contains text, images, video, animation, sound files, and 3D objects (Suwichai, 2014). It also motivates users by attracting their attention with its striking visual and auditory features (Tolentino et al., 2009). In AR technology, two main methods combine the real and virtual worlds, which are optical and video-based (Azuma, 1997). In the optical-based method, virtual images created by a computer are superimposed on the real world through glasses. In the video-based method, images of the real world captured through devices such as tablets or smartphones are combined with virtual images by a computer and displayed on the screen (Somyürek, 2014). In brief, whether it is optical-based or video-based, a device (e.g., tablet, smartphone, AR glasses) is needed to display virtual objects in the real world. Three main elements are required to implement AR technology: hardware, software (Craig, 2013), and tracking/markers (Phan & Choo, 2010).

Hardware: The hardware of augmented reality systems consists of at least three components: sensors, processors, and displays. Sensors detect data from the real world. Processors analyze sensor input, execute AR application tasks, and provide appropriate signals for display. Displays process all processors' signals to integrate the virtual and real worlds. This convinces users that the virtual items in the scenes they view on computers, tablets, smartphone screens, head-mounted displays, or AR glasses exist in the real world (Craig, 2013).

Software: Software enables the hardware to perform a task. These software programs not only run AR applications but can also create or generate content for AR applications (Craig, 2013). Several software development kits (SDKs) are available for developing AR applications, including ARToolkit, Vuforia, and Aurasma, among the most widely used and free software development tools. In addition, programs such as Unity3D and Google SketchUp can design 3D models compatible with the SDKs for 3D objects in AR applications (İçten & Bal, 2017b).

Tracking / Markers: Tracking is one of the most critical components of AR systems, as it enables the correct positioning of virtual objects in the correct location. In an AR system, markers are used to track the user's point of view and display virtual objects in the real world (Phan & Choo, 2010). Markers are tools that combine the real and virtual environments by being detected by cameras and allowing interaction between the two (İçten & Bal, 2017a; Sünger & Çankaya, 2019). Wojciechowski & Cellary (2013) have classified AR applications as marker-based, markerless-based, and location-based. In marker-based applications, specially designed colored or black-and-white patterned images, called markers, are placed in the real environment, and the AR application can easily recognize them through the camera (Altınpulluk, 2018; Craig, 2013). These markers are used to display 3D objects in the real world. The most widely used markers are Quick Response (QR) codes (Cheng & Tsai, 2013; Figueiredo et al., 2014). In markerless-based AR applications, image recognition is performed through the camera using the natural properties of physical objects instead of markers placed in the environment. In location-based applications, the location of mobile devices is recorded using GPS, and real-time information related to the geographic location is provided to users (Altınpulluk, 2018; Cheng & Tsai, 2013; Wojciechowski & Cellary, 2013). The AR application process can be summarized as follows:

The user sends the image to the AR software by directing the camera toward the marker. The AR software recognizes the marker, creates a 3D image, and then combines the 3D image with the real image captured by the camera. These two images, which are merged in reality and virtually, are visible on the user's computer, tablet, or smartphone screen, and thus, the AR effect occurs. (Martins et al., 2015).

3. Related Studies and the Gap in the Field

When the literature was examined, it was seen that there are a significant number of content analysis studies on the use of AR in education, and according to the results of these studies, the most common educational fields were science, mathematics, foreign language, and social science (Altınpulluk, 2019; Bacca et al., 2014; Chen et al., 2017; Fidan & Tuncel, 2018; Kara, 2018; Sırakaya & Alsancak Sırakaya, 2018). In music education, a limited number of studies have examined the use of this new technology. Turchet et al. (2021) examined 199 current studies published in the last ten years that introduced Expanded Reality (XR), which is a combination of VR, AR, AV, and MR, defined Musical XR, and brought together various application areas (e.g. composition, education, performance, sound engineering) related to Music and XR. These studies, which cover technological, artistic, perceptual, and methodological fields, were analyzed according to the categories of research type, main functions, target users, social experience, and connectivity. Based on the results, in XR technology, application studies were more numerous than theoretical ones focused on VR technology. In addition, the most studied areas were performance and music education. In musical performance, VR applications were most commonly used within Expanded Reality (XR) technology, while AR applications were most commonly used in music education. In a study by Serafin et al. (2017), examples of virtual reality applications were given. It was emphasized that these applications could be an alternative to children acquiring musical skills. In addition, the potential contributions of AR applications to music education were also mentioned. Another study (Yang, 2020) is about modern technologies (e.g., video-based e-learning, computer software, MIDI) applied in piano education. The features of several AR applications (e.g., Vicon Mx 3D Project, AR Piano System, Keynvision, and Andantino) among these modern technologies were introduced, and the effectiveness and limitations of these applications in music education and instrument training were discussed. In a review study by Kalkanoğlu (2020), five augmented reality applications (Piano 3D-AR, Guitar 3D-AR, Tonic-AR, Note Blast, and Music.iLuv) designed for music education on the IOS mobile operating system were introduced, and the advantages and disadvantages of these applications were discussed.

As seen in the examples given above, it can be understood that the review studies involve other dimensions of the music field (e.g. composition, performance, sound engineering), in addition to education, either by examining AR technology together with other modern technologies or by introducing AR applications that exist in the music field. In this regard, no research has been found that comprehensively examines studies focused on augmented reality technology specifically in “music education”.

This research, which examines the studies that have been conducted thus far regarding the current subject, is considered important in terms of determining general trends in research topics and methods used, revealing the advantages and limitations of the AR technology applied, and guiding researchers who will work in the field by directing future studies according to the results obtained. Therefore, this study will fill the gap in the literature by analyzing the studies on the use of augmented reality technology in music education.

4. Purpose of the Study

The purpose of this study is to examine the studies on augmented reality applications used only in music education regarding descriptive features, methodological features, and outcomes and to reveal trends related to these studies. The research questions are as follows:

1. What are the descriptive features of the studies on augmented reality in music education?

    - What is the distribution of the studies according to the years?
    - What is the distribution of the studies according to the number of authors?
    - What is the distribution of the studies according to the type of publication?
    - What is the distribution of the studies according to the authors’ countries of affiliation?
    - What is the distribution of the studies according to the subjects?
    - What is the distribution of the studies according to the type of AR?

2. What are the methodological features of the studies on augmented reality in music education?

    - What is the distribution of the studies according to the research models?
    - What is the distribution of the studies according to the research sample?
    - What is the distribution of the studies according to the data collection tools?
    - What is the distribution of the studies according to the data analysis methods?

3. What are the outcomes of the studies on augmented reality in music education?

   - What are the advantages of the AR applications used in the studies?

   - What are the limitations of the AR applications used in the studies?

5. Methodology

5.1. Research Design

This research is a qualitative study using the descriptive survey model. In the descriptive survey, the existing state, event, or object is described as it is in the present or past (Karasar, 2012). Since this research aims to determine the current status of the studies on AR applications used in music education in the literature, the model of the research has been determined as the descriptive survey model.

5.2. Research Sample

The study group for this research consists of studies on the use of augmented reality technology in music education in the WoS and Scopus databases. The reasons for selecting these databases for the study are as follows:

- They have the most comprehensive literature among the existing databases.
- They are among the most prestigious and well-known databases in the world.
- They contain high-quality publications as a result of the peer review process.
- Full-text publications can be easily accessed.

The studies included in this research are limited to the period up to 2020. In this paper, the criterion sampling method, one of the purposive sampling methods, was used. Purposive sampling is the intentional selection of people, places, or situations with specific characteristics to obtain the best information related to research questions (Cohen et al., 2018; Creswell, 2013; Patton, 2002). Criterion sampling is a method in which all situations that meet specific criteria, either created by the researcher or previously determined, are considered (Cohen et al., 2018; Yıldırım & Şimşek, 2021). The researcher must decide which type of purposive sampling will be most effective (Creswell, 2013). Since the researcher in this study determined specific criteria, the criterion sampling method was used.

5.3. Selection Criteria

The publications used for the relevant study were selected based on the criteria listed below. Accordingly, the publications included in the study group should;

1) cover the period up to December 2020,

2) be peer-reviewed,

3) consist of articles and conference proceedings with full-text access,

4) contain AR applications only used in music education,

5) be English-language publication.

Book chapters, poster presentations, reviews, and studies that are not related to the educational dimension of the music field were not included in the sampling and were excluded from the criteria.

5.4. Selection Process

Since the study group for this research consists of publications related to AR applications, studies related to virtual reality (VR) were excluded. In the literature search for the publications used in the study, the relevant keywords were kept as broad as possible. Therefore, in addition to the keywords "augmented reality" and "music education," others representing these terms were also considered and used as keywords. Moreover, since mixed reality is defined as the combination of real and virtual environments and AR is located between these two environments (Milgram et al., 1995), the keyword "mixed reality" was also added. In this regard, articles published in peer-reviewed journals and full-text conference proceedings covering the period from the beginning to 2020 (including 2020) were included in the search. Accordingly, the searches conducted in the WoS and Scopus databases are as follows:

Search on WoS

TOPIC: (("augmented reality" or "augmenting reality" or “mixed reality”) AND ("music education" or "musical education" or "music learning" or "music teaching" or "music*" or "instrument education" or "instrument learning" or "instrument teaching"))

Refined by: DOCUMENT TYPES: (PROCEEDINGS PAPER OR ARTICLE) AND LANGUAGES: (ENGLISH) AND 2021 (EXCLUDE- PUBLICATION YEARS)

Search on Scopus

TITLE-ABS-KEY (("augmented reality" OR "augmenting reality" OR "mixed reality")) AND TITLE-ABS-KEY (("music education" OR "musical education" OR "music learning" OR "music teaching" OR "music*" OR "instrument education" OR "instrument learning" OR "instrument teaching"))) AND (EXCLUDE (EXACTKEYWORD , "Virtual Reality")) AND (LIMIT-TO (SRCTYPE, "p") OR LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (LANGUAGE, "English") AND PUBYEAR < 2021

According to the search results, 353 studies were listed in the WoS database (150 studies) and the Scopus database (203 studies). After 274 studies (WoS: 121 and Scopus: 153) unrelated to the research subject based on the titles and abstracts were excluded, 22 duplicate studies found in both databases were eliminated. Four out of the remaining 57 studies were excluded because the full text could not be accessed. The full texts of the remaining 53 studies were read, and a preliminary review was carried out. As a result of the evaluations, it was determined that six studies were not related to the "education" dimension of the music field, three studies were related to simulation rather than AR, four studies were reviews, three studies were book chapters, and two studies were poster presentations; therefore, they were eliminated. The remaining 35 studies were included in the analysis process of the research, and the flow chart is shown in Figure 3.

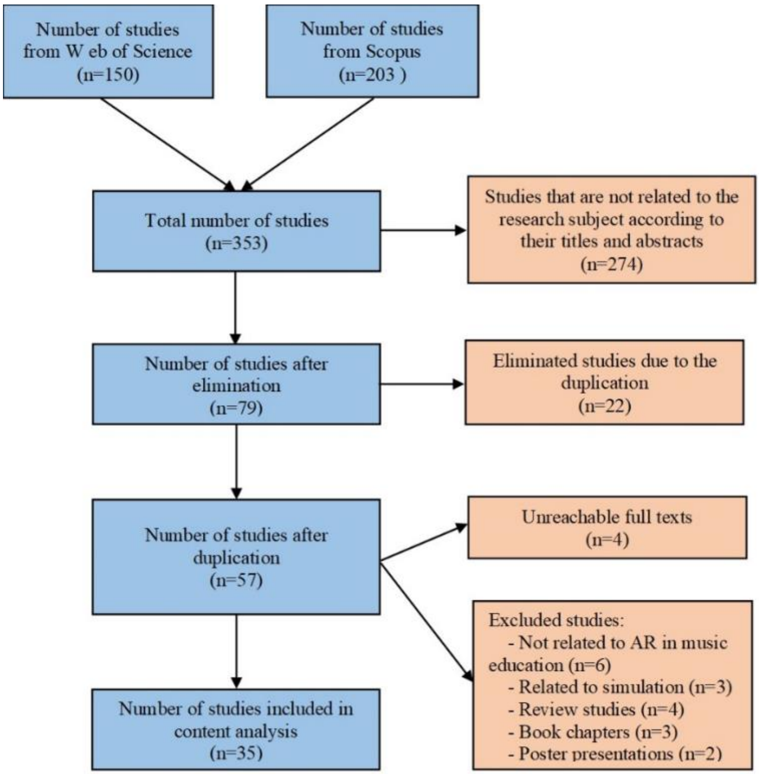

Fig. 3. Flow chart of the selection process

5.5. Data Collecting Tools

The data used in the research were obtained by the document analysis method. Document analysis is a systematic process of thoroughly reviewing or evaluating the contents of printed and electronic written sources (Bowen, 2009). Since this study's purpose is to analyze studies on AR applications used in music education, document analysis was used as the data collection method.

A publication classification form was used to organize data related to studies in a planned and systematic way. For this purpose, the Paper Classification Form (PCF) created by Sözbilir et al. (2012) and Göktaş et al. (2012) was used as an example and revised according to the subject, purpose, and research questions of the study. The revised draft form was presented for the opinions of two experts in the field of measurement and evaluation in education. Based on the expert opinions, the final form of PCF consists of seven categories: 1) paper information, 2) research subject, 3) research design, 4) research sample, 5) data collection tools, 6) data analysis, and 7) advantages and limitations of AR applications. In addition, a "Notes" section was added to the bottom of the form to allow the researcher to take notes while reviewing the publications.

The data collection process for the study covers the period from January 2021 to December 2021. Furthermore, a literature review was conducted from January 2021 to July 2021; the abstracts of all the obtained publications were read, and a preliminary assessment was made. Publications that were not related to the research topic were eliminated. From July 2021 to December 2021, the full texts of the studies that were given a preliminary assessment were read, and decisions were made on the publications that would constitute the study group. Accordingly, 35 studies were transferred to the publication classification form and prepared for analysis.

5.6. Data Analysis

The data from the reviewed publications were analyzed using the content analysis method. Content analysis is a method for categorizing and interpreting scientific data coded within the framework of predetermined or later developed categories and emerging themes, synthesizing and drawing theoretical conclusions

(Cohen, Manion, & Morrison, 2018; Finfgeld-Connett, 2014). This research used the content analysis method to clearly explain the data obtained from examining the publications within the specified time range using specific themes, categories, and codes.

Content analysis allows for qualitative and quantitative analysis of the obtained data (Lune & Berg, 2017). Additionally, Büyüköztürk et al. (2020) mention that frequency and percentage values can commonly be used when interpreting the data obtained through content analysis. Accordingly, the data (codes) containing the categories under the themes that constitute the descriptive and methodological features of the publications were converted into numerical data showing frequency values using the Statistical Package for the Social Sciences (SPSS) 22 program, interpreted by using tables and charts for ease of understanding and presented in the results section. Additionally, data on the advantages and limitations of AR applications used in music education, which are included under the theme of the outcomes, were coded, compiled under relevant categories, and interpreted. The theme-category-code relationships and explanations of the examined publications are shown in detail in Table 1 below.

Table 1.

Theme-category-code details of the reviewed publications

Themes	Categories	Codes	Explanations
Descriptive Features	Paper Information	Authors	Number of authors
		Years	Publishing year
		Publication types	Article, proceeding
		AR type	Marker-based, markerless-based, other, not specified
		Country	Authors' country of affiliation
	Research Subject	Music theory education	Ear training, harmony, and other
		Instrument education	Piano, strings (violin, viola, cello, contrabass), guitar, wind instruments (flute, clarinet, oboe, etc), and other instruments
		Voice training	Singing
		Prototype development	Prototype
		Other subjects	Creativity, music history, etc
Methodological Features	Research Design	Quantitative research	Experimental, survey, correlational, casual-comparative, and other
		Qualitative research	Case study, ethnography, phenomenological, grounded theory, and other
		Mixed research	Explanatory, exploratory, embedded, and other
		Other design	Action research, user experience research, etc.
	Research Sample	Preschool	Preschool students, preschool teachers
		K-12 students	Kindergarten, primary school, secondary school, high school
		K-12 teachers	Kindergarten, primary school, secondary school, high school
		Institute	Undergraduate students, postgraduate students, academic staff
		Other samples	(i.e. Teacher candidates, parents, etc.)
	Data Collection Tools	Achievement tests	Open-ended, multiple-choice, and other
		Questionnaires	Open-ended, Likert, and other
		Scales	Multiple-choice, Likert, and other
		Interview	Structured, semi-structured, unstructured, focus group
		Observation	Participant, nonparticipant
		Other tools	AR applications, smartphones, tablets, etc.
	Data Analysis	Quantitative_Descriptive Statistics	Frequency/percentage, central tendency measures, and other
		Quantitative_Inferential Statistics	t-test, ANOVA, MANOVA, correlation, regression, non-parametric tests, and other

		Qualitative	Thematic analysis, content analysis, and other
Outcomes	Advantages / Limitations of AR Apps	List of advantages	The advantages of the AR applications used in music education
		List of limitations	The limitations of the AR applications used in music education

5.7. Validity and Reliability

Validity and reliability are considered two essential criteria for scientific research in terms of the cogency of the results. Methods used to measure validity and reliability in quantitative studies are not available in qualitative studies; however, certain precautions can be taken to increase validity and reliability. (Yıldırım & Şimşek, 2021). In qualitative studies, it is necessary to describe in detail every stage of the research, from data collection methods to presenting findings and results, and to present it in a convincing narrative that persuades the reader (Büyüköztürk et al., 2020; Creswell, 2013; Yıldırım & Şimşek, 2021). The process and precautions taken to ensure validity and reliability in this research are as follows:

- The reasons for selecting the Web of Science and Scopus databases and the search criteria used in these databases to access publications related to the research topic were described in detail.

- It is clearly stated which criteria were used in selecting the publications obtained by the criteria sampling method.

- Categories that provide a systematic classification of the data obtained from the reviewed publications were created by a detailed examination of content analysis studies on AR applications in different educational fields in the literature (Fidan & Tuncel, 2018; İçten & Bal, 2017a; Kara, 2018; Korucu et al., 2016). To systematically code the data relevant to these categories, the researcher created a paper classification form based on the forms published by Sözbilir et al. (2012) and Göktaş et al. (2012), which was presented to field experts to ensure the validity of the scope.

- The data obtained from the publications were independently coded by the researcher and an expert with a Ph.D. in music education into the paper classification form. Similar results were obtained when the coding was compared. In cases of disagreement, a consensus was reached between the researcher and the expert through discussion, and the discrepancies were resolved. This ensured the reliability of the research.

- The data was transferred to the SPSS 22 program for analysis of the publications, and it was reviewed twice at a one-week interval to ensure that all of the data was correct.

- The method followed in analyzing the data was described in detail.

- The results were presented in their original form and discussed by relating them to the relevant literature in the field.

5.8. Ethical Consent of the Research

In this study, data were obtained through the document analysis method since the aim was to examine publications related to augmented reality applications used in music education. No data were collected from any participant or subject using surveys, interviews, or observations. Therefore, there was no need for ethical committee approval.

6. Results and Discussion

In this section, 35 accessible studies related to the research subject were analyzed by considering the themes determined as descriptive features, methodological features, and outcomes, and the categories created based on sub-problems. The findings were discussed in relation to the literature.

6.1. Descriptive Features of the Studies on Augmented Reality in Music Education

6.1.1. Distribution of the Studies according to the Years

The distribution of the studies according to years is shown in Figure 4.

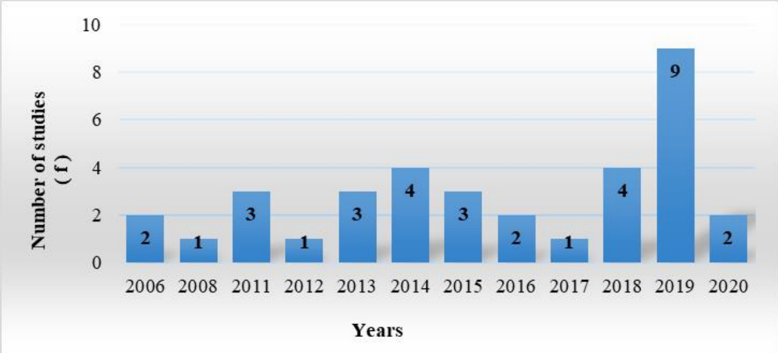

Fig. 4. Studies according to the years

Based on the findings, studies on AR used in music education began in 2006. Upon reviewing the literature, it was seen that in 2003, Berry et al. developed a prototype called the "Music Table" for composing musical patterns by arranging cards with QR codes on a table. This AR application, used to concretize the abstract elements of music through computer-generated images, was used for educational purposes in the same authors' study titled "Tunes on the Table" (Berry et al., 2006). Additionally, in the same year, in a study conducted by Motokawa and Saito (2006), AR technology was applied to assist beginners in guitar education using visual guides such as chord names and finger positions of the chords with the help of a virtual hand model. Based on this information, it is believed that music education studies related to AR technology began in 2006.

When Figure 4 is examined, it can be seen that the number of studies in the field increased in two different periods: 2014 (f=4) and 2018 (f=4), however, the most common studies were conducted in 2019 (f=9). When studies on other educational fields using AR technology were examined, it was found that the majority of studies were also conducted in the same year (Garzón et al., 2020; Palancı & Turan, 2021; Theodoropoulos & Lepouras, 2021; Türker, 2021). In this case, it is understood that the use of AR in education became widespread in 2019 due to the interest in AR technology in almost all fields in recent years. This increase is thought to have positively affected studies related to music education as well.

6.1.2. Distribution of the Studies according to the Number of Authors

The distribution of the studies according to the number of authors was examined and shown in Figure 5.

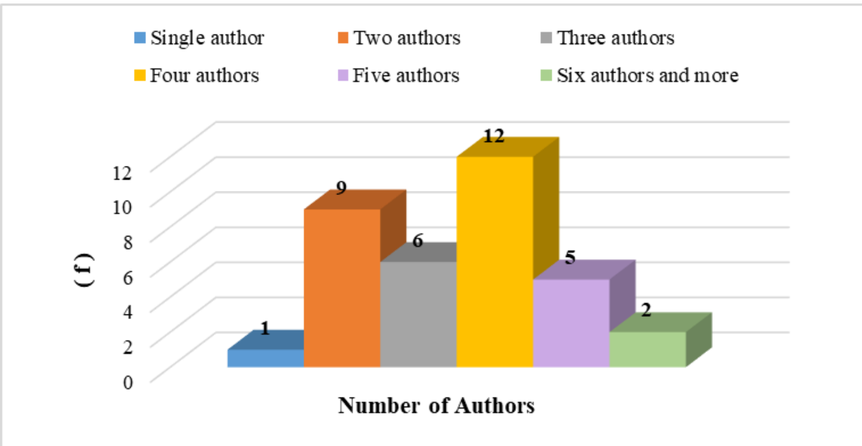

Fig. 5. Studies according to the number of authors

Accordingly, it was found that only one study was single-authored, while all the other studies (f=34) were co-authored. Most studies were four-authored (f=12) and then two-authored (f=9). The least number of studies were found with six or more authors (f=2). According to Figure 5, almost all the studies examined had multiple authors. This may be because research on AR applications consists of different stages, such as preparation, design, and implementation, and therefore needs to be carried out in collaboration by different authors (Kuzu, 2014, as cited in Fidan & Tuncel, 2018). Additionally, since AR is a new technology applied in the field of education, the need for multi-authored studies may arise to prepare these studies with an interdisciplinary approach (Palancı & Turan, 2021).

6.1.3. Distribution of the Studies according to the Publication Type

This research was limited to articles and full-text conference proceedings scanned in the WoS and Scopus databases. The distribution of the studies based on publication type is shown in Figure 6.

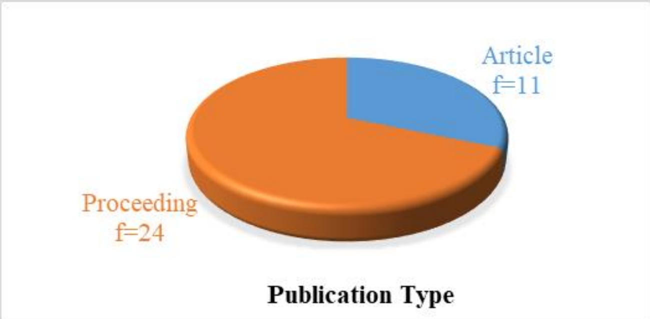

Fig. 6. Publication type

According to the findings, most studies on augmented reality applications in music education were published as proceedings (f=24). A similar result was also obtained in a study by Palancı and Turan (2021).

6.1.4. Distribution of the Studies according to the Authors' Countries of Affiliation

The studies using AR applications in music education were conducted in many countries. The distribution of the studies according to the authors' countries of affiliation is shown in Figure 7.

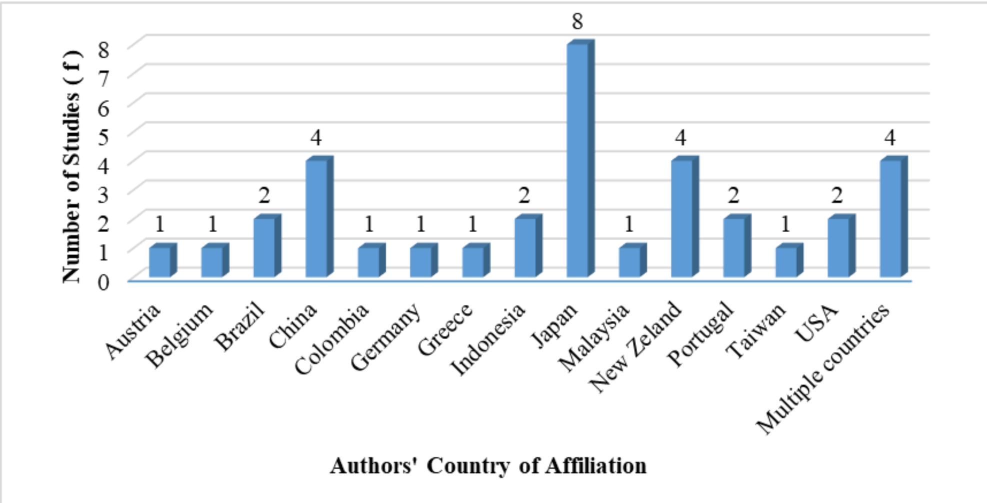

Fig. 7. Authors' country of affiliation

When Figure 7 is examined, it was seen that the most significant number of studies were conducted by researchers in Japan (f=8), followed by researchers in China and New Zealand (f=4).

Considering that Japan and China are technologically advanced, AR-related studies may be concentrated in these two countries. Billinghurst (2018) states that Japan is among the countries with the most researchers working in AR technology. According to research conducted by Yıldız (2019), the number of studies on AR applications has increased, most of these applications are integrated with education, and Japan is the primary source of such research. In addition, it was announced in March 2021 that AR technology was added to the list of critical industries in China's 14th Five-Year Plan (Zhang et al., 2021). Based on this information, it can be understood that a large number of studies on AR have been conducted in these two countries in many areas, and research on AR is still ongoing. Therefore, it can be said that the concentration of studies on AR in music education in these countries is a natural result of this situation.

Moreover, according to the research findings, several studies were conducted jointly by researchers from different countries and were listed under the heading "multiple countries" (f=4). The countries in which these joint studies were conducted are Spain and Mexico (Del Rio-Guerra et al., 2019; Martin-Gutierrez et al., 2020), Spain and France (Rusiñol et al., 2018), and Germany and the USA (Rogers et al., 2014). When studies on the use of AR technology in other educational fields are examined, it was observed that the USA and Spain are among the countries where the most research on this subject has been conducted (Erbaş & Atherton, 2020; Kara, 2018; Palancı & Turan, 2021). However, according to the data of this research, a different situation emerged, and it was understood that a limited number of studies were conducted on music education in these two countries.

6.1.5. Distribution of the Studies according to the Research Subjects

AR technology is most commonly used in instrument training (f=28) among the basic dimensions of music education, including theory, instrument, and vocal training as shown in Table 2.

Table 2.

Studies according to the subjects

Research Subject		Number of Studies (f)
Music Theory Education		2
Instrument Education (f=28)	Piano	14
	Strings (Violin)	1
	Guitar	8
	Wind instruments	0
	Other instruments	5
Voice Training		0
Prototype Development		26
Other Subjects (f=5)	Creativity	1
	Music history	2
	Early childhood music education	2

According to the findings, these studies, aimed at beginners, mainly focused on piano (f=14) and guitar (f=8) education. When the literature is examined, studies showing similarities with these findings have been found. Accordingly, the study by Serafin et al. (2017) stated that AR applications in the music field were mainly used for piano or guitar learning, and Turchet et al. (2021) emphasized that the piano was the most frequently investigated in research on AR technology. In this regard, these results align with this study's findings.

It can be understood from Table 2 that AR technology is only used in violin training among the string instruments (f=1), and no studies have been conducted on the use of this technology for other strings (viola, cello, contrabass). In the category of other instruments (f=5), only one study is related to the drum kit (Yamabe et al., 2011), while the others are related to traditional instruments from China, Malaysia, and Indonesia. These traditional instruments, which are in danger of being forgotten due to people's preference for modern musical instruments or the higher prices of traditional instruments from East Asia, were introduced to and taught to the younger generation using AR technology to help preserve and promote them (Juniawan & Sylfania, 2019; Permana et al., 2019; Tan & Lim, 2019; Zhang et al., 2015). Furthermore, research was not found on the use of AR technology in voice training or wind instrument training (e.g., flute, clarinet, oboe). Under the heading of music theory education, there are two studies (f=2) that use AR technology to teach notes on the staff (Correa et al., 2016) and musical perception in terms of pitch, rhythm, intensity, duration, and timber (Martins et al., 2015).

Furthermore, the research findings showed that 26 studies were related to prototype development. When the publications constituting the study group were examined, it was found that most of these prototype development studies were also related to instrument training in music education.

Apart from these, studies in which AR technology was used in the fields of creativity (f=1), music history (f=2), and early childhood music education (f=2) are mentioned under the heading "other subjects." For the development of creativity, an augmented reality system called the "Music Table" was used, which allows users to move objects represented by markers on the table to create music. This application concretizes music heard abstractly through computer-generated images. Children aged 6–11 were asked to use instrument cubes and blocks representing notes to create the shape of a given theme (e.g., an animal figure) and create a musical composition. In this manner, short and simple musical phrases with music patterns were played according to the shape created. This helps to develop the creativity of children who have just started music education (Berry et al., 2006).

In two studies on the theme of "the aesthetic periods of music history" by Gomes et al., digital content, including videos, audio, and 3D models, was used and activated through QR codes. In the first study, students were asked to use their mobile devices (smartphones or tablets) to find eight stations scattered around the school using a game-based learning activity called Musical Peddy and then use QR codes to display digital clues containing audio, images, videos, and graphics that answered questions about music history at each station. With this digital content, students correctly identified 20th-century composers, musical instruments, and musical styles (Gomes et al., 2014). The other study organized an AR Music Gallery exhibition consisting of A3-sized posters with QR codes containing audio, video, 3D models of musical instruments, and text information. The observations showed that students were exceedingly interested in exploring the AR content and were highly motivated to learn about music history (Gomes et al., 2015).

One of the studies on early childhood music education examined the effectiveness and feasibility of mobile devices and AR technology in facilitating the learning of preschool and kindergarten students. The learning content (rhythm, pitch, song structure, meaning of lyrics, bodily expression of music, and information about musical instruments) taught through the use of QR codes in the "Treasure Hunt" game are elements of the music curriculum taught in preschool and kindergarten. According to the results of the study, it was observed that children of this age showed interest in the game, mobile devices, and QR codes as part of AR technology; they learned new things about music and AR technology through game-based learning; and they exhibited collaborative behaviors by seeking help from and providing support to classmates in other teams. In this regard, it has been found that AR technology is a strong tool for attracting and maintaining children's interest in music while also developing their cognitive skills, collaboration skills, and social relationships during the learning process (Preka & Rangoussi, 2019).

In another study, music scores, lyrics, animations related to the story of the song, and virtual keyboards containing the sounds of instruments such as the piano, violin, flute, or saxophone were immersed in the pages of the "Augmented Songbook" using AR technology. Musical notes on the virtual keyboard and animations were colored with the help of an AR application and displayed on mobile devices in real time without any unique markers. The goal was to teach abstract musical concepts to preschool students by concretizing them. According to the data obtained from the study, the prototype that was developed received positive feedback from both preschool students and their parents after being tested in real-world environments (Rusinol et al., 2018).

6.1.6. Distribution of the Studies according to the AR Type

When the AR types used in the publications were examined, it was seen that different types, such as marker-based, markerless-based, and projection-based types, were used in the applications.

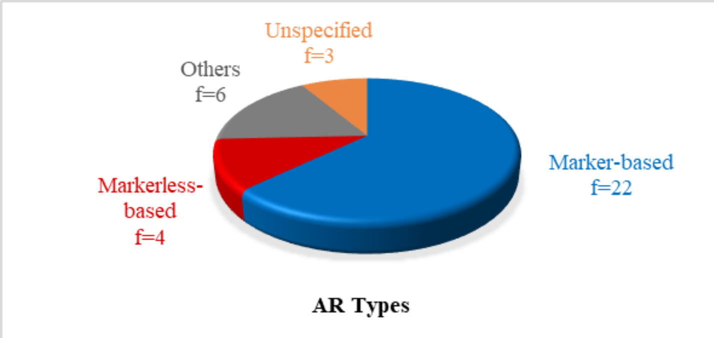

Fig. 8. Distribution of the AR types

According to Figure 8, it was observed that the marker-based AR type was the most preferred in music education studies using AR applications (f=22). These results are also consistent with studies on AR applications in other educational fields (Altınpulluk, 2018; Bacca et al., 2014; Fidan & Tuncel, 2018; Sırakaya & Alsancak Sırakaya, 2018).

In Figure 9, the distribution of AR types by year is shown.

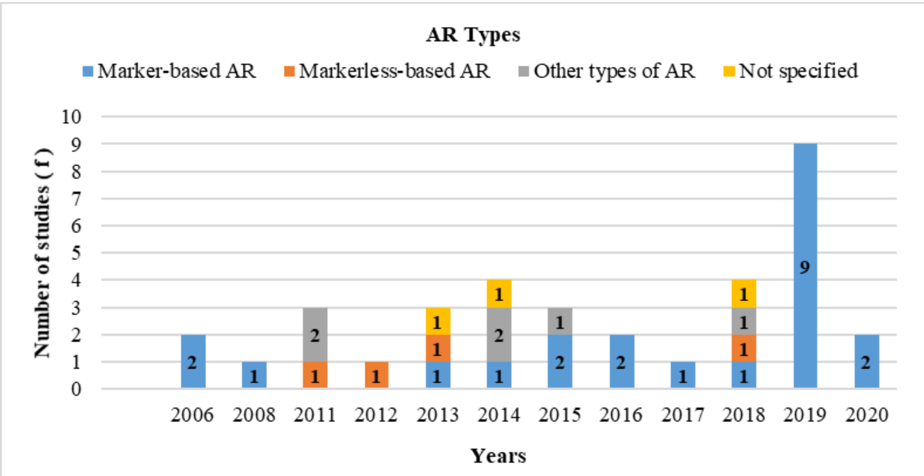

Fig. 9. Distribution of AR types by year

It is seen that while the number of studies utilizing the marker-based AR type was entirely limited between 2006 and 2018 (f=1, f=2), considering studies conducted in 2019, this type of AR is the most preferred one (f=9). The ease of development and use of marker-based AR types may explain why they have been increasingly preferred over other AR types in recent years (Altınpulluk, 2018).

According to Figure 8 and Figure 9, markerless-based AR is used in a limited number of studies (f=4). When these studies were examined, it was understood that this type of AR was used in instrument training (De Sorbier et al., 2012; Goodwin & Green, 2013; Huang et al., 2011) and early music education (Rusiñol et al., 2018). Apart from these, projection-based AR was used in six studies (Löchtefeld et al., 2011; Raymaekers et al., 2014; Rogers et al., 2014; Sun & Chiang, 2018; Yamabe et al., 2011; Zhang et al., 2015) and indicated in the "others" category (see Figure 8). With projection-based AR, digital information can be directly reflected onto any physical surface in the real world, and users can interact with the reflected digital information (Craig, 2013; Yakubova et al., 2021).

Regardless of the type of AR, specific software is needed to develop these applications. According to the examined studies, these applications were developed using various software such as Aurasma, Vuforia, Unity 3D, ARToolkit, Maya 3D, and Layar. Among them, Unity 3D and Vuforia were the most preferred software, and in almost all studies, mobile devices (smartphones and tablets) were used to display the developed AR designs.

6.2. Methodological Features of the Studies on Augmented Reality in Music Education

6.2.1. Distribution of the Studies according to the Research Design

The distribution of the studies according to the research design was examined and shown in Table 3 in detail.

Table 3.

Studies according to the research design

Method	Design	Number of studies (f)
Quantitative (f=6)	Experimental	6
	Survey	0
	Correlational	0
	Causal- Comparative	0
	Quantitative other	0
Qualitative (f=2)	Case study	2
	Ethnography	0
	Phenomenological	0
	Grounded theory	0
	Qualitative other	0
Mixed (f=2)	Explanatory	1
	Exploratory	0
	Embedded	1
Others (f=16)	Action research	1
	User experience research	15
Unspecified		9

When Table 3 was examined, it was seen that different research models were used. Accordingly, the quantitative studies (f=6) conducted in the experimental model were related to piano and guitar education (Keebler et al., 2013, 2014; Li, 2018; Rio-Guerra et al., 2019; Rogers et al., 2014; Sun & Chiang, 2018); the qualitative studies in the case study model (f=2) were conducted in musical perception and music history (Gomes et al., 2014; Martins et al., 2015).

As a result of content analysis, it was found that both quantitative and qualitative data were used in certain studies. The findings obtained from quantitative data in these studies were supported by researchers' observation notes and user opinions expressing the feelings and thoughts of participants about AR applications. The researcher evaluated these studies in the mixed-method category. Accordingly, one of these studies (Martin-Gutierrez et al., 2020) was evaluated under the explanatory design category due to using qualitative data to provide a more detailed explanation of quantitative data. The other (Zhang et al., 2015) was evaluated under the embedded design category as both quantitative and qualitative data were collected simultaneously, and qualitative data supported quantitative data. When examining Table 3, it can be seen that action research and user experience methodologies are included under the "Others" category. Creswell (2015) argues that action research should not be considered a qualitative research method, as it allows for using both qualitative and quantitative data collection techniques and, therefore, should be considered a separate method. Consequently, action research was classified in the "Others" category in Table 3. In this study, it was found that this type of research model was used in only one study on early childhood music education (Preka & Rangoussi, 2019). On the other hand, in user experience studies (f=15), a prototype was developed and presented to users for their experience, and their opinions were stated in the results of the study (Berry et al., 2006; Chow et al., 2013; Gomes et al., 2015; Juniawan &

Sylfania, 2019; Kerdvibulvech & Saito, 2008; Löchtefeld et al., 2011; Molloy et al., 2019; Motokawa & Saito, 2006; Permana et al., 2019; Raymaekers et al., 2014; Rigby et al., 2020; Rusiñol et al., 2018; Tan & Lim, 2019; Torres & Figueroa, 2018; Yamabe et al., 2011). These studies have not been considered design-based models but have been explained under "user experience." According to Hassenzahl & Tractinsky (2006), user experience is defined as "the consequence of a user's internal state (predispositions, expectations, needs, motivations, mood, etc.), the characteristics of the designed system (e.g., complexity, purpose, usability, functionality), and the context (or the environment) within which the interaction occurs (e.g., organizational/social setting, the meaningfulness of the activity, voluntariness of use, etc.)" (p. 95). In a design-based model, the generated prototypes must be revised based on feedback from participants. As Kuzu et al. (2011) described, in design-based research, certain modifications are made to enhance its functionality after a design or prototype is developed and tested. These modifications are then tested on the same design or prototype, and this process is repeated until the prototype functions as intended. Therefore, since the prototypes developed in the publications are not redesigned and presented to users based on the opinions obtained from their experiences, related studies are defined as "user experience research" rather than "design-based research."

In addition, nine studies without defined a research model were identified as related to the topics of AR-assisted piano and violin instruction and AR-assisted music notation instruction (Cai et al., 2019a, 2019b; Correa et al., 2016; De Sorbier et al., 2012; Fernandez et al., 2016; Goodwin & Green, 2013; Hackl & Anthes, 2017; Huang et al., 2011; Zeng et al., 2019).

The distribution of the research models included in the studies according to the years was examined and shown in Figure 10.

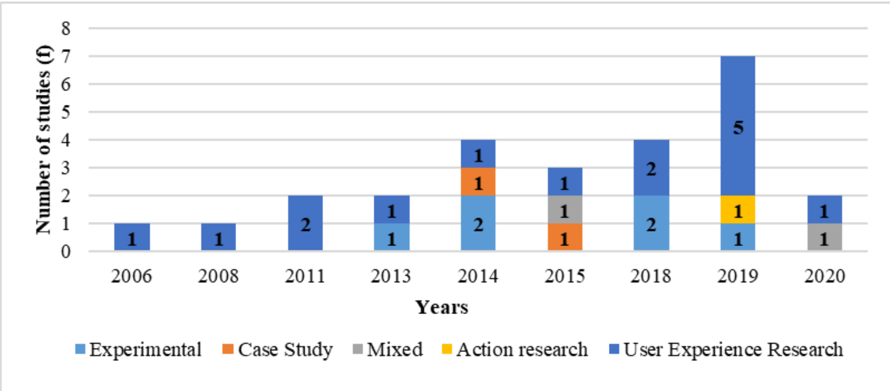

Fig. 10. Distribution of research design by years

Accordingly, it can be said the user experience research model started in 2006 and particularly increased in 2018 and 2019, while the experimental model was first used in 2013. Figure 10 shows that the first usage of the action research model and the highest frequency value of user experience studies were carried out in 2019. It can be said that studies have shown a trend toward user experience research in recent years, and different research models have also been carried out. In addition, case studies and mixed studies have not shown any increase over the years.

6.2.2. Distribution of the Studies according to the Research Sample

As seen in Table 4, the sample group in the examined studies include different educational levels (preschool, kindergarten, primary school, and undergraduate).

Table 4.

Studies according to the sample groups

Research Sample		Number of Studies (f)
Pre-school (f=1)	Pre-school students	1
	Pre-school teachers	0
K-12 Students (f=9)	Kindergarten	3
	Primary school	5
	Secondary school	0
	High school	0
	Mixed	1
K-12 Teachers (f=2)	Kindergarten	0
	Primary school	2
	Secondary school	0
	High school	0
Institute (f=8)	Undergraduate	7
	Postgraduate	0
	Academic staff	0
	Mixed	1
Other (Teacher candidates, parents, etc.)		15

In a study by Sırakaya & Alsancak Sırakaya (2018), it was found that AR technology was used at almost every educational level, from primary school to the undergraduate level. Thus, this result is similar to the findings of the current study. On the contrary, another study conducted by Bacca et al. (2014) stated that none of the studies using AR applications in the field of "early childhood education" had been carried out and that children in this age group might not be ready to use this technology. However, in subsequent years, certain studies that included preschool and kindergarten students in the sample group were conducted. Studies in which AR technology is used in music education can be given as examples (Correa et al., 2016; Preka & Rangoussi, 2019; Rusiñol et al., 2018). Considering the level of students constituting the research sample, most of the participants were selected from K–12 students (f=9). A study on the use of XR technology in the field of music highlights the increasing use of AR technology in music education programs for children (Turchet et al., 2021). This result supports the findings of the research.

Table 4 also reveals that several studies were also conducted with undergraduate students (Keebler et al., 2013; Keebler et al., 2014; Li, 2018; Martin-Gutierrez et al., 2020; Molloy et al., 2019; Rigby et al., 2020; Rio-Guerra et al., 2019) (f=7). Considering AR technology is most commonly used in instrument training (Table 2), undergraduate students may have been preferred for the sample due to their advanced cognitive and physical capabilities in instrument training compared to K–12 students. In addition, the examined studies show that most participants in the research sample were beginners in instrument education; in contrast, intermediate- and advanced-level students only participated in a limited number of studies. Furthermore, it is understood from the findings that there were a small number of studies in which primary school teachers participated (Martins et al., 2015; Tan & Lim, 2019), and no studies in which academic staff included in the study group were found. Additionally, in one study, undergraduate and postgraduate beginner-level students were included in the sample group and indicated as the "mixed" category (Torres & Figueroa, 2018).

In addition to all these findings, it can be seen that the distribution of studies according to the sample type is focused on the "other" category (f=15). However, since the ages or grades of the participants in the examined studies were not specified, they could not be included in the sample groups in the categories of preschool, K-12 students, K-12 teachers, or institutes. Therefore, they were collected under the "other" category. The study groups under this category consisted of participants such as volunteers with no experience in instrumentation (Chow et al., 2013; De Sorbier et al., 2012; Kerdvibulvech & Saito, 2008; Molloy et al., 2019; Motokawa & Saito, 2006; Permana et al., 2019; Raymaekers et a., 2014; Rogers et al., 2014; Sun & Chiang, 2018; Yamabe et al., 2011; Zeng et al., 2019; Zhang et al., 2015), parents (Rusinol et al., 2018), and professional musicians (Löchtefeld et al., 2011; Martin-Gutierrez et al., 2020; Rogers et al., 2014).

6.2.3. Distribution of the Studies according to the Data Collection Tools

The data collection tools used in the publications include questionnaires (f=13) and scales (f=8) for quantitative data, and observations (f=11) and interviews (f=9) for qualitative data.

Table 5.

Studies according to the data collection tools

Data Collection Tools		Number of Studies (f)
Achievement Test (f=0)	Open-ended	0
	Multiple choice	0
	Other	0
Questionnaire (f=13)	Open-ended	2
	Likert	7
	Mixed	1
	Other	3
Scale (f=8)	Multiple choice	0
	Likert	6
	Other	2
Interview (f=8)	Structured	1
	Semi-structured	4
	Unstructured	3
	Focus group	0
Observation (f=10)	Participant	1
	Non-participant	9

According to the findings in Table 5, the most commonly used data collection tools are questionnaires for quantitative research and observations for qualitative research. In the examined studies, it was found that Likert-type questionnaires and scales were more commonly used, and in particular, scales were in the form of usability scales (Juniawan & Sylfania, 2019; Martin-Gutierrez, 2020; Molloy et al., 2019; Rigby et al., 2020; Rio-Guerra et al., 2019). In addition, semi-structured interviews (Martins et al., 2015; Tan & Lim, 2019; Yamabe et al., 2011; Zhang et al., 2015) and observations conducted with non-participants (Berry et al., 2006; Correa et al., 2016; Gomes et al. 2015; Martin-Gutierrez et al., 2020; Martins et al., 2015; Prega & Rangoussi, 2019; Rusinol et al., 2018; Tan & Lim, 2019; Zhang et al., 2015) were preferred.

Achievement tests are among the most commonly used data collection tools in recent studies on the use of AR technology in other education fields (Arıcı et al., 2019; Kara, 2018; Sırakaya & Alsancak Sırakaya, 2020; Turhan et al., 2022). However, when examining the data in Table 5, it can be seen that achievement tests were not used in any studies. Considering that most of the studies on the use of AR are conducted in the fields of natural science, mathematics, computer technologies, and foreign language, which are primarily based on theoretical subjects, it is natural for achievement tests to be among the most commonly used data collection tools. However, since all publications included in this research were based on practices in music education and none of the studies evaluating academic success related to the theoretical aspect of music education were found, it can be stated that achievement tests were not preferred. In addition, the “other” categories seen in Table 5 consist of questionnaires that do not specify the question types (Gomes et al., 2014; Molloy et al., 2019) and training and performance rating scales that use a different evaluation system (Keebler et al., 2013; Keebler et al., 2014).

The sample group of this research consists of 35 studies. Since several studies used more than one data collection tool, the total frequency in Table 5 is indicated as 39.

6.2.4. Distribution of the Studies according to the Data Analysis

The distribution of the studies according to the data analysis was examined and shown in Table 6.

Table 6.

Studies according to the data analysis

Data Analysis		Number of Studies (f)
Quantitative (f=17)	Only descriptive statistics	11
	Only inferential statistics	2
	Descriptive and inferential	4
Qualitative (f=13)	Thematic analysis	0
	Content analysis	1
	Other	12
Mixed (f=2)	Quantitative and qualitative	2

Based on the findings, quantitative (f=17), qualitative (f=13), and both quantitative and qualitative (f=2) analysis methods were used in the examined studies. Therefore, it can be understood that the most commonly used data analysis method is quantitative analysis. The fact that quantitative analyses are the most commonly used method in research on the use of AR in different fields of education also supports this finding (Chen et al., 2017; Fidan & Tuncel, 2018; Kara, 2018; Sırakaya & Alsancak Sırakaya, 2018). In other words, regardless of the field, it can be said that quantitative analyses are primarily used in studies on the use of AR technology in education.

Five studies in the category of quantitative analysis used frequency/percentage and mean calculations from descriptive statistics techniques (Chow et al., 2013; Kerdvibulvech & Saito, 2008; Sun & Chiang, 2018; Torres & Figueroa, 2018; Zeng et al., 2019). On the other hand, six studies utilize a rating system consisting of different calculation methods (e.g., Handheld Augmented Reality Usability Scale-HARUS, Usability Evaluation Method-UEM), and therefore these studies are also evaluated within the context of descriptive statistics (De Sorbier et al., 2012; Fernandez et al., 2016; Goodwin & Green, 2013; Huang et al., 2011; Juniawan & Sylfania, 2019; Permana et al., 2019). In addition, ANOVA was used in studies that utilized inferential statistics techniques (Keebler et al., 2013; Keebler et al., 2014), while frequency/percentage, central tendency measures (mean), t-test, ANOVA, and non-parametric Mann-Whitney U tests were conducted in studies that utilized both descriptive and inferential statistics techniques (Li, 2018; Rigby et al., 2020; Rio-Guerra et al., 2019; Rogers et al., 2014).

According to Table 6, the content analysis method used in one study was included in the qualitative analysis methods category (Preka & Rangoussi, 2019), and direct observations notes and user opinions were included in twelve studies and indicated under the "other" option (Berry et al., 2006; Correa et al., 2016; Gomes et al., 2014; Gomes et al., 2015; Löchtefeld et al., 2011; Martins et al., 2015; Molloy et al., 2019; Motokawa & Saito, 2006; Raymaekers et al., 2014; Rusinol et al., 2018; Tan & Lim, 2019; Yamabe et al., 2011). In addition, two studies in which both qualitative and quantitative data analysis methods were utilized are listed under the "mixed" category (Martin-Gutierrez et al., 2020; Zhang et al., 2015). In these studies, frequency/percentage, mean, t-test, and ANOVA were used for quantitative analysis, while interview and observation techniques were used for qualitative analysis.

Furthermore, it was determined that data analysis was not carried out in three studies (Cai et al., 2019a; Cai et al., 2019b; Hackl & Anthes, 2017). These studies aimed to design prototypes utilizing augmented reality

(AR) technology and investigate their implementation approach in the context of piano education. The functionality of the designed prototypes is unknown due to a lack of user studies. However, it is thought that these studies also contribute to instrument education.

6.3. Outcomes of the Studies on Augmented Reality in Music Education

6.3.1. Advantages of AR Applications used in the Studies

It has been revealed that there are numerous advantages of AR applications used in music education in the examined studies. These advantages are coded and shown in Figure 11.

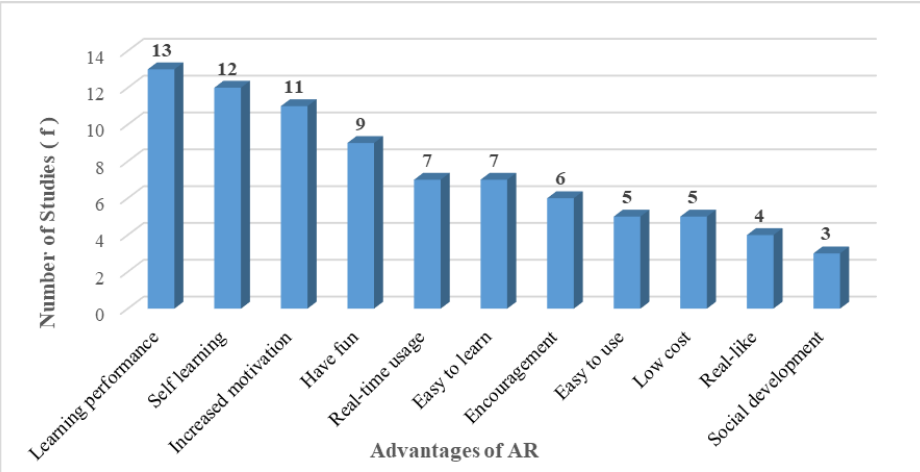

Fig. 11. Advantages of AR apps used in music education

The contributions of AR applications that affect learning positively were identified as the most commonly observed advantages in the publications related to the study group. They were arranged under the code of "learning performance" (f=13). Based on these findings, AR applications used in music education accelerated learning in beginners as they supported active learning (Fernandez et al., 2016; Gomes et al., 2015; Keebler et al., 2014; Martin-Gutierrez et al., 2020; Rogers et al., 2014; Sun & Chiang, 2018), enabled to be more effective than traditional methods (such as chord diagrams, tablature, etc.) in helping students succeed in musical instrument training (Keebler et al., 2013; Zhang et al., 2015). In addition, these applications were found to be more effective in developing cognitive skills in preschool students, such as understanding music notation and recognizing musical instruments, and helping them learn in more detail (Correa et al., 2016; Preka & Rangoussi, 2019).

Other significant advantages identified in the studies were increased motivation (f=12) and self-learning (f=11) codes. According to studies on the code of increased motivation, AR applications made learning more attractive and enjoyable than traditional methods, such as teacher-centered instruction. The feedback provided in these applications helped users contribute to the learning process. Additionally, several studies identified that students were motivated by the use of game-based approaches and the ability to interact with 3D graphics in some applications (Chow et al., 2013; Fernandez et al., 2016; Gomes et al., 2014; Juniawan & Sylfania, 2019; Martin-Gutierrez et al., 2020; Molloy et al., 2019; Preka & Rangoussi, 2019; Rio-Guerra et al., 2019; Yamabe et al., 2011).

Self-learning refers to studies in which beginner-level students, in particular, can learn to play instruments using visual guides created with AR technology or virtual hand positions projected on the instrument (Goodwin & Green, 2013; Huang et al., 2011; Keebler et al., 2013; Löchtefeld et al., 2011; Martin-Gutierrez et al., 2020; Motokawa & Saito, 2006; Rigby et al., 2020; Rio-Guerra et al., 2019; Rogers et al., 2014; Torres & Figueroa, 2018; Yamabe et al., 2011). In this way, students can independently learn basic information related to their instruments without needing a teacher in the early stages of their education (Kularbphettong et al., 2019, as cited in Martin-Guiterrez et al., 2020). However, these applications should not be considered a substitute for individual face-to-face instruction with a teacher but rather as complementary practices to traditional teaching methods.

Studies conducted by Yamabe et al (2011), Rio-Guerra et al (2019), Martin-Gutierrez et al (2020), and Rigby et al (2020) indicated that students were more motivated when they learned the relevant subject on their own through AR applications. In this case, it can be said that self-learning and motivation have complementary advantages, which positively impact learning performance. The fact that these advantages are in the top three in Figure 12 supports this idea.

Other advantages of using AR applications in music education include 1- the compatibility with game-based learning, and their attractive feature of being entertaining for children compared to traditional instrument teaching methods (Berry et al., 2006; Cai et al., 2019a; Li, 2018; Martins et al., 2015; Molloy et al., 2019; Zhang et al., 2015); 2- the ease of learning basic music concepts and instrument playing (Correa et al., 2016; Keebler et al., 2014; Martins et al., 2015), and the encouragement of beginner students to learn theoretical subjects and make music with their instruments (Berry et al., 2006; Gomes et al., 2014; Gomes et al., 2015; Raymaekers et al., 2014); 3- real-time usage with the display of virtual images (highlighted colors, virtual fingers, virtual frets, etc.) on real instruments (Cai et al., 2019b; De Sorbier et al., 2012; Goodwin & Green, 2013; Huang et al., 2011; Rigby et al., 2020; Torres & Figueroa, 2018; Zeng et al., 2019); 4- the opportunity to know and learn to play traditional instruments from different countries in a realistic 3D form (Juniawan & Sylfania, 2019; Permana et al., 2019); 5- the ability to develop teamwork skills through specific applications, which contribute positively to the social development of students (Berry et al., 2006; Gomes et al., 2014; Preka & Rangoussi, 2019); and finally, 6- the economic aspect of AR applications that can be accessed via mobile devices such as smartphones, tablets, or laptops, and a webcam. The decrease in costs related to AR technology in recent years has made it more accessible compared to previous years (Kapucu & Yıldırım, 2019; Yıldız, 2019), thus making its use possible in various education fields, including music education.

Many of the advantages listed in Figure 11 are similar to the findings of other educational studies in which AR applications are used (Bacca et al., 2014; Batdi & Talan, 2019; Chen et al., 2017; Chiang et al., 2014; Di Serio et al., 2013; Kara, 2018; Lee, 2012; Özaydın Aydoğdu & Eryilmaz, 2019; Somyürek, 2014). Therefore, considering that today's modern educational approach is intertwined with technology, it is pleasing to see that these advantages provided by AR applications will also be effective in music education, as in other education fields.

6.3.2. Limitations of AR Applications used in the Studies

It has been observed in the examined studies that there are certain limitations in the use of AR applications in music education as well as advantages. The limitations that arise from the difficulties encountered while using these applications are presented in Figure 12.

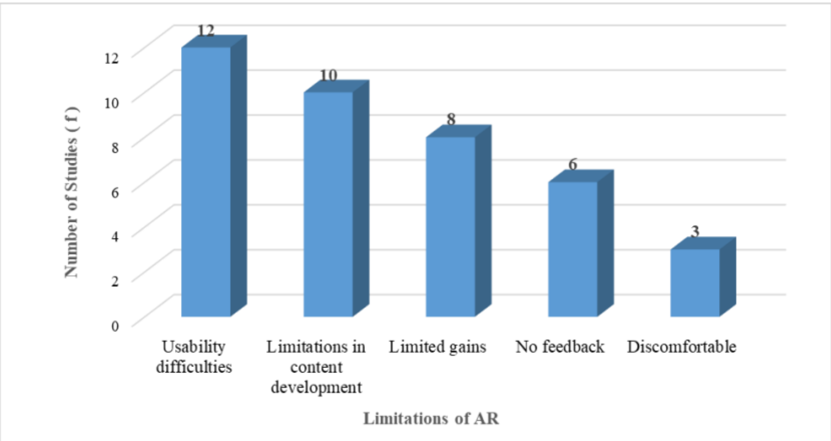

Fig. 12. Limitations of AR apps used in music education

Accordingly, usability difficulties (f=12) and limitations in content development (f=10) are the most common limitations encountered in the AR applications. According to studies conducted by Akçayır & Akçayır (2017), Kara (2018), and Özaydın Aydoğdu & Eryılmaz (2019), technical and usability issues were among the most frequently mentioned limitations. This also supports the findings obtained in this study.

AR applications developed in every field may have specific limitations and shortcomings. In this research, it was observed that the shortcomings in the visual guide information included in some AR applications used in instrument training caused certain limitations in content development and difficulties in use. For instance, in applications related to guitar education, displaying the guitar from only one perspective (e.g. front view) can cause problems understanding certain positions. It was stated that the positions of top and side perspectives should also be displayed (Motokawa & Saito, 2006). Moreover, there was a need to develop visualization to better express the colors of the strings and fingers in the reflected image for finger techniques (Martin-Gutierrez et al., 2020; Rio-Guerra et al., 2019; Zhang et al., 2015). In addition, the lack of finger numbers on virtual piano rolls was one of the difficulties for beginner students (Molloy et al., 2019). Apart from these, other difficulties that arise during use included the insufficient size of the smartphone screen for applications (Tan & Lim, 2019) and the limited field of view for AR applications displayed with HMDs (Chow et al., 2013; Hackl & Anthes, 2017; Rigby et al., 2020; Zeng et al., 2019). In this regard, it can be said that limitations in content development may cause difficulties in use.

Furthermore, several studies stated that the markers were not fully perceived due to insufficient lighting, This situation lead to the inefficient use of applications due to their incorrect operation and caused problems for students (Sun & Chiang, 2018; Tan & Lim, 2019). In a study conducted by Akçayır & Akçayır (2016) on the use of AR applications in foreign language education, it was found that technical problems, such as the inability to recognize the marker and the small size of the display screen, were mainly determined. This result is consistent with the limitations encountered in using AR applications in music education. As a consequence, it can be thought that the inability to recognize markers and the limitations of the field of view are common problems in AR applications.

According to Figure 12, other limitations revealed from the studies are indicated by the codes of limited gains (f=8), no feedback (f=6), and discomfortable (f=3). The term “limited gains” refers to the limitations in the gains related to music education in which AR technology is used in the studies under consideration. For instance, the applications developed by Goodwin & Green (2013) and Rio-Guerra et al. (2019) were limited to teaching only basic major chords or scales. These applications contain basic-level information as they are applied to beginner-level participants.

In the studies mentioned under the title "no feedback", the usability levels of the developed applications (how usable they are) could not be understood as feedback from the users was not requested (Cai et al., 2019a; Cai et al., 2019b; Fernandez et al., 2016; Hackl & Anthes, 2017; Huang). et al., 2011; Sorbier et al., 2012). In addition, discomforts that are caused by long-term use of HMDs and recently developed hololens have been expressed with the code “discomfortable” (Molloy et al., 2019; Rigby et al., 2020; Torres & Figueroa, 2018). In this regard, Molloy et al. (2019) state that, despite technological developments, HMD is still not suitable for long-term use.

7. Conclusion

In this research, studies related to the use of augmented reality technology in music education scanned in the WoS and Scopus databases until 2020 were analyzed, the descriptive features, methodological features, and advantages and limitations of the AR applications used were revealed, and summarized as follows:

- AR technology has been used for music education since 2006, and most of these studies were proceedings published mainly in 2019. When the study group was examined based on countries, it was found that researchers in Japan, China, and New Zealand carried out the most studies. Some of the studies were also conducted collaboratively by researchers from different countries (Spain-Mexico, Spain-France, Germany-the USA). Despite being related to music education, the majority of the authors of these studies were in the field of computer science, and a lack of music educators among the co-authors of the studies was observed. Naturally, the development process of AR applications is directly related to the field of computer science, and authors conduct that related studies in this field. However, it should be noted that interdisciplinary, collaborative studies with music educators can also contribute to this technology's widespread use in music education.

- When considering the basic dimensions of music education as theory education, instrument education, and voice training, the distribution of subjects in the studies that constitute the study group was examined with these dimensions, and it was found that the studies tended to focus on prototype development in the field of instrument education aimed at beginner-level students. It was observed that the developed prototypes were mainly focused on piano and guitar education, and none of the studies using AR technology were found in the training of wind instruments (e.g. flute, clarinet, oboe, etc.) or strings (viola, cello, contrabass) other than the violin. Furthermore, it was concluded that a limited number of studies in the field of music theory had been carried out, and there was a lack of studies focused on vocal training using AR technology.

- According to the methodological features of the studies examined, it was revealed that the most commonly used methodology was user experience. It was observed that the studies conducted in recent years showed a tendency toward this type of research. In addition, experimental, case study, mixed, and action research models were also used in the study group publications.

- As a result of the research, it was determined that the most preferred sample group was K-12 (kindergarten and primary school) and undergraduate students. None of the studies included the participation of academic staff, secondary and high school students, or teachers.

- Various data collection tools, such as questionnaires, scales, observation, and interviews were used in the studies examined. In particular, recent research has shown a widespread use of usability scales in these studies. It was also observed that achievement tests were not applied in any of the studies. Additionally, while descriptive statistical techniques were most commonly used in quantitative data analysis, direct observation notes were included, and user opinions were described in the qualitative data analysis.

- Based on the study's findings, it has been revealed that AR applications used in music education have certain advantages. These advantages include 1) the effectiveness of 3D-supported applications in improving cognitive skills and facilitating learning; 2) their attractive and entertaining nature due to their game-based approach, which increases motivation and success, particularly in instrument training; 3) the ability to create an environment for self-learning for beginners by providing visual guides such as rolling notes and virtual hands; 4) the ability to be used in real-time due to the visualization of virtual information on real instruments; 5) developing teamwork skills and social development through some applications that allow collaboration; 6) the economic aspect of being easily accessible via mobile devices.

- In addition to the advantages revealed in the research, certain limitations were also identified related to these applications: 1) technical difficulties, such as markers not being fully perceived due to insufficient lighting, 2) the screens of mobile phones not being large enough and limitations related to the field of view of the HMD, 3) limited gains in music education due to specific limitations in content development, 4) the limited use of HMD and HoloLens due to discomfort caused by long-term use.

8. Suggestions and Future Work

Augmented reality technology can concretize abstract concepts and visually enrich elements that are difficult to understand, thereby positively contributing to the learning process, particularly for children. One of the most significant characteristics of today's children is their close following and utilization of technological advancements. The new generation can remarkably adapt to the various technological innovations brought by the digital age, and they can utilize technology-related tools quickly and efficiently, enhancing their creativity. Therefore, it is believed that integrating augmented reality technology into music education can positively impact students' creativity levels if incorporated into schools' art education programs, provided that the necessary infrastructure is in place. In this regard, interdisciplinary collaborations could be carried out with music educators to explore the potential of augmented reality technology in music education.

According to research, AR applications used in music education have been developed for beginners. However, developing applications for intermediate- and advanced-level students is also possible. Additionally, the research findings indicate that most AR applications are focused on instrumental education, particularly in the categories of piano and guitar. Future research could prioritize less explored or unexplored areas such as music theory, strings, wind instruments, and vocal training.

There is a lack of research on using augmented reality technology in music education for students with disabilities among the studies examined. Developing AR applications specifically tailored for these students could enable them to participate in music education actively. For instance, the differences between the durations of the notes (whole note, quarter note, eighth note, etc.) or intervals expressing the distance between two sounds can be visualized with AR technology and made concrete for hearing-disability students.

To minimize the limitations encountered when using augmented reality applications in music education, it is essential to test and evaluate the applications and make necessary adjustments after gathering participant feedback. This can be done by conducting a design and development model in future studies.

This research involves studies conducted until (and including) 2020. In future research, the utilization of AR technology in music education can be examined by analyzing studies conducted from 2021 onward. Thus, trends and developments in the use of AR technology in music education can be identified, and the evolution of its implementation can be determined.

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