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Interactive piano training using augmented reality and the Internet of Things

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Abstract

The technology of augmented reality in education is a significant attempt to reform the training mode and develop education in general. Piano training usually includes using well-known computer means of teaching music on-screen and hardware. In this context, augmented reality (AR), alone and integrated with the Internet of Things (IoT), is a promising solution for interactive piano learning. The present study seeks to investigate the impacts of an AR and IoT assisted system for piano education on learners' musical literacy and piano skills (resonance, rhythm, coherence, pace, fingering, playing with both hands and legato playing). As an interactive learning environment, the study integrates HoloKeys, an AR application. This research builds on an empirical approach through a quasi-experiment. It involved 100 students of Tourism College of Zhejiang, China. The study participants were divided into control and experimental groups. The results showed that the experimental group achieved significantly higher results in a piano course than the control group. Hence, it confirms the positive perspective of using AR and the IoT in piano training. The research results can be useful to design and implement modern piano training courses. Thanks to the advantages that AR and IoT technologies offer when shaping interactive learning environments, the application of the present findings goes beyond music education and has the potential to boost learning in other specialties. Future research should focus on designing and developing AR learning tools and additional learning resources. These instruments will provide students with high-quality technical support for piano training.

Keywords Augmented reality · Digital technologies in music · Internet of Things · Music · Piano · Piano skills

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1 Introduction

The IoT is a specialized algorithm system that combines computing hardware with modern digital technology. The essence of the IoT is a kind of code designed to transmit arrays of data (Lv et al., 2020). At the same time, the concept of AR should be identified with the ability to refine real and virtual information to create an optimal paradigm. AR is capable of using any computer-generated virtual information to design specific situations that can be applied in the real world (Zhang, 2020). The types of information described are complementary and help in achieving an improved update of the reality world. A lot of work has been done recently to develop IoT and AR technologies. Hence, it makes their application possible or available in various fields, including music education (Lv et al., 2020; Simion et al., 2021).

Scholarly research indicates the effectiveness of attending music lessons in the context of improving students' cognitive and creative development (MacDonald, 2013). There are certain approaches in computer-assisted music instruction. One is on-screen (e.g., Piano or Yousician—users need to perform a visual transfer of information from the device to apply it to a particular musical instrument), and the other is hardware-based (e.g., The ONE Smart Piano—able to provide direct guidance, but user engagement rates are reduced and the problem of facilitating this process is not solved) (Simion et al., 2021). A promising idea for computer-based piano instruction is the use of AR (Rigby et al., 2020; Zeng et al., 2019). AR can serve as a kind of connector between the student and the information system to gain practical skills with the tool. The use of AR in music education can help solve the problem of a shortage of qualified personnel in music education institutions. Research on this type of education is becoming much more widespread (Trujano et al., 2018).

The use of digital technology in the context of enhancing music students' perception of material is not a new area of research into the implementation of virtual interactivity in music education (Trujano et al., 2018). On the other hand, none of the aforementioned programs provide spatially accurate visual representations. Smart Music is software used in music education that gives apt feedback on a musician's playing skills (SmartMusic, 2022). The user has access to sheet music and strips, which indicates the current moment in the process. The main tool for this program is the microphone, which determines whether the user is playing the notes correctly while playing the song. This system provides the user with relevant statistics. For example, it indicates which sections had the most errors. Smart Music is based only on musical notation and does not offer an intuitive representation of the music composition. Synthesia allows one to learn to play the piano and, like ARPiano, presents songs in the form of a piano keyboard (SynthesiaGame, 2022). The notes are represented by a rectangle, it gradually approaches the desired key on the virtual keyboard. This approach is intuitive, unlike simple musical notation, and provides the user with the opportunity to learn the patterns in the song. One can also see the results of music playing in the app. In addition, it shows statistics to help them navigate their practice (Trujano et al., 2018). Synthesia also provides an intuitive visual representation of a song through a traditional two-dimensional display. Moreover, this program aims at comparing performance in real-time using virtual keyboard. It should be noted that Andante and Perpetual Canon are the projects developed in the research paradigm of the MIT Media Lab (XiaoSquared, 2022a, b). These programs can perform visualizations of live music in piano performance. However, for the purposes of the current study, these programs would serve a limited function—only analysis, not teaching (Trujano et al., 2018).

The current scientific literature lacks sufficient empirically validated data on the impact of AR and IoT technology on the development of musicians' practical skills. A challenge was taken to address this gap. Hopefully, this study can fill in the missing data, as the use of AR and IoT for educational purposes continues to gain popularity.

2 Literature review

2.1 AR and IoT in music teaching

Music education has a long tradition in the field of AR. Users see a visual overlay of notes displayed flatly in their field of view. The display of add-ons starts only when the user looks at the hands. The type of notes depends on which hand this person is looking at. Augmentation is not registered (e.g., it does not have a direct spatial connection with a real object), unlike the approach displayed in the present research. HMD (Das et al., 2017) is used for the display. The information about which string to pull on the guitar to reduce cognitive gaps (compared to the traditional way of learning the instrument) was updated. For the first time, researchers described the interaction that needs to be performed on the instrument (Hackl & Anthes, 2017). Fiducial markers contribute to registering the guitar and the virtual hand. Other researchers have focused on the educational level of learning to play the piano using AR. They proved that add-ons and gamification components increase the motivation and interest in learning to play the piano. They presented a system illustrating the notes to be played using lines approaching the keys. In addition, their results show that musical literacy does not increase when using their illustration system (Chow et al., 2013). An introduced virtual character illustrates how well the pianist played. To interpret the music played, scientists compare input from a MIDI keyboard with an initially loaded MIDI file (Fernandez et al., 2016). Some researchers have used a similar analysis before (Hackl & Anthes, 2017). Researchers have used revisors (for tracking) and a desktop AR system equipped with a webcam and a traditional screen. In terms of visualization, they demonstrate the system in the realm of spatial AR, where they project the keys to be pressed directly onto the piano. In different modes, for example, the app can display the current key and the next key to be pressed. If the user presses the wrong key, this system is highlighted in red to provide feedback (Weing et al., 2013).

2.2 Using AR technology to create scenarios for learning to play the piano

Technologies can present information dynamically, and in this way, they contribute to the transformation of the educational environment. In turn, it is situational piano instruction that is based on the theory and practice of cognitive learning. This theory suggests that students' participation in general cultural practices based on social context shapes the paradigm of individual structural knowledge (Li, 2018). Knowledge gained in specific situations is more powerful and useful than general knowledge. Therefore, the formation of knowledge among students should include educational activities in specific physical or social situations (Wang & Cheng, 2016). The theory of situational cognition has the following statement: practicing various learning activities in an educational situation contributes to improving the learning outcomes and cognitive intelligence of students. The AR technology facilitates creating the educational situation within learning to play the piano for students. Piano learning is a dynamic system in which various factors in the learning process are interrelated. Moreover, these factors interact with each other (Huang et al., 2016). In AR, the user sees virtual objects superimposed on or combined with the real world; this technology has become especially valuable and popular in recent years (Hackl & Anthes, 2017). It goes far beyond simple advertising and virtual aids, from professional development to sophisticated remote collaboration scenarios. The use of AR for teaching musical instruments has a long tradition in the field. However, the rapid development of AR Head-Mounted-Displays (HMDs) has greatly expanded its field of application (Hackl & Anthes, 2017).

2.3 AR-applications for piano playing in the IoT environment

Among the most famous and significant virtual piano systems is Synthesia. This system allows one to add MIDI files of specific songs that one can fully listen to and play (Julia et al., 2019). The software processes the files and visually formats the notes to display the keys to be pressed, along with their duration. Unfortunately, using Synthesis has its drawbacks. For example, a user needs to have a computer on which the program is running. In addition, it necessitates using the keyboard to follow the notes. The HANDEL music learning app does not have a simplified version of the display for those who cannot read sheet music. Instead, it uses the sheet music itself, augmented on the keyboard (Hackl & Anthes, 2017). It requires a transparent display on the head so that the user's hands can freely interact with the keyboard. The practical session begins by uploading a musical score to the program, where it is processed by the user language of the musical score. Subsequently, it continues with a pianist's nod meaning the readiness to practice. No notes are displayed until the user focuses on the hands playing the piano. The display shows scores in a fixed position to avoid confusion with keys flying all over the keyboard along with a moving hand: notes are displayed on the right side of the display for the right hand and similarly for the left hand. Phase correlation analysis is used to determine if the student's head is turned to the left or right. Another Android app called AR

Musical (Lemos et al., 2017) engages students in learning activities and gets them motivated and interested. This application contributed to evaluating the effectiveness of teaching musical notation to children. Another application for studying the piano called HoloKeys can superimpose the keys for playing in an AR environment (Hackl & Anthes, 2017). This application uses MIDI files to process melodies and interprets the keys along with their durations. This system can accurately track piano keys with a marker. In the menu, users can select the specific song to play, the speed, and the playback mode in which they can navigate to a specific position in the piece. In addition, they can select a calibration mode in which they can adjust the position of the marker on the piano so that the optimum magnification is displayed (Molero et al., 2021). In addition, the peculiarity of this system is that musical works can be displayed in two different ways. The first one presupposes the process when a note becomes highlighted at the moment when it needs to be played. The second one uses the Beatmania way when the next notes can be seen in advance. The FunPianoAR (Zeng et al., 2019) was created in 2019. This system is notable for its concept of a pair game in which one player plays the melody of the right hand, and the other focuses on the notes of the left hand. In this application it is necessary to apply an HMD, because one needs AR smart glasses to play, which are necessary to make note additions appear on the keyboard. FunPianoAR is a system capable of displaying keys in a different way: a colored cube is superimposed on the note to be played at a particular moment, and an outline cube appears on the notes to be pressed (Molero et al., 2021). There is also an arrow overlay feature (based on four fiducial markers on the keyboard) that shows the direction the user needs to look if the note being played is suddenly not in their field of view (Zeng et al., 2019). The few AR applications described earlier are based only on overlaying instructions on the keyboard that allow the user to press the necessary notes in time. In 2016, there was the introduction of another AR system that calculates a score based on the pianist's playing to provide feedback (Fernandez et al., 2016). This example demonstrates the high importance of getting feedback when learning to play the piano. This system is unique in the way feedback is delivered, namely through a visualized 3D virtual character. In addition, the necessary equipment consists of a computer keyboard or electronic MIDI keyboard, a pair of Google Cardboard, and a smartphone. Players can add MIDI files that they want to practice (Simion et al., 2021). Similar to other systems, the screen interprets and displays notes above the keyboard so that the user knows which keys to press. The rectangles shown above the buttons serve as note duration identifiers. The evaluation consists of comparing the originally imported MIDI files with the data received by the pianist during performance. In this way, the feedback module receives a score. It should be noted that the audio and visual feedback provided by the program using AR technology can stimulate multiple channels of learning simultaneously and help develop students' visual, auditory, and motor skills (Bauer et al., 2019; Chang et al., 2020; Di Serio et al., 2013).

Having studied the literature on the application of AR and IoT in music education, the following gaps were identified. Student achievement in music and piano education in an AR- and IoT-enabled environment has been little researched. However, it is important not only to introduce modern methodological solutions into training, but also to study the effectiveness of such integration. Also, the impact of the described technologies on the development of practical skills of playing musical instruments is practically not studied.

2.4 Objectives

The study seeks to investigate the impacts of an AR and IoT assisted system for piano education on learners' knowledge of the piano theory and piano skills (resonance, rhythm, coherence, pace, fingering, playing with both hands, legato playing). As an interactive learning environment, the study integrates HoloKeys, an AR application. The objectives of the present study are to:

- determine if there is a difference in the level of knowledge in the two groups before the intervention.
- identify whether there is a significant difference between the academic achievements in both groups after the intervention.
- define whether there is a significant difference between the students in both groups regarding the retention of piano skills
- ascertain the effectiveness of using AR and the IoT in music education.

Research hypotheses:

H1: Using an AR-assisted app (HoloKeys) for learning the piano will improve students' knowledge of the piano theory.
H2: Using an AR-assisted app (HoloKeys) for learning the piano will improve students' piano playing skills.

3 Methods and materials

This study involved the use of the HoloKeys program. This program aims to teach piano based on AR and the IoT. It is a prototype implementation of an AR tool for learning to play the piano. HoloKeys runs on an HMD that the user wears while sitting in front of a physical piano. The app shows the notes to be played by displaying virtual keys overlaid on the physical keyboard, using two different approaches. By dynamically acquiring musical data by loading and processing MIDI (Musical Instrument Digital Interface) files, the program is completely independent of the musical compositions to be taught. The present research implied studying the impact of AR on students' academic performance in piano lessons through assessing students in both groups before the intervention (pre-test) and after its completion (post-test).

3.1 Participants

The present research builds on an empirical approach. It involved a total number of 100 students of Tourism College of Zhejiang in China. Thus, the study participants were randomly divided into two groups: control (students received conventional training) and experimental (students underwent modified training using AR and IoT tools). Both groups were formed in accordance with the principles of the experimental model. Both groups contained fifty students. The experimental group included 23 female and 27 male students. The average age of students in the experimental group was 19.11 ± 0.83 years. The control group contained 28 female and 22 male students. The average age of students in the control group was 19.26 ± 0.89 years. The students enrolled in the classes under the study had similar socio-economic backgrounds.

3.2 Research design

Before the intervention, the study participants passed a pre-test regarding the assessment of their educational achievements. Students underwent full-time training conducted in classes. Four teachers trained study participants. These teachers had more than ten years of teaching experience and a Ph.D. degree in music education. In addition, their teaching style was the same. Classes in both groups lasted twenty hours (two-hours sessions ten times) within the curriculum. The classes included a presentation of theoretical material and then its practical development through learning to play the piano under the supervision of a teacher. Teaching in groups was carried out with the help of traditional methods: students used notebooks, theoretical material was studied with the help of books or teacher's slides, practical skills were practiced on an acoustic piano. Compared to the control group, students in the experimental group received traditional learning with additional use of the HoloKeys application. Upon the completion of the study plan, students underwent a previously developed post-test to evaluate their piano achievements. Subsequently, the data obtained were processed and analyzed. The scheme of the study is presented in Fig. 1.

3.3 Data collection

The data collection included using a performance test and observing the piano playing skills. The researchers studied the influence of the curriculum based on AR and the IoT on the success and consolidation of music knowledge among students. They also studied the course curriculum and the expert opinions while developing the piano achievement test scale. The study results regarding the content of the piano learning achievement test proved its validity. In addition, the researchers have prepared two test questions that reflected each acquisition. Accordingly, they formed

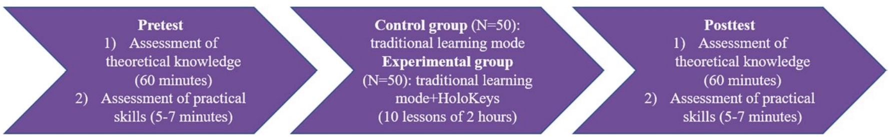

Fig. 1 Scheme of the learning process

30 questions in total for the piano lesson. Verifying the compliance of the pilot test questions with the achievements and principles of scale development and ensuring the content validity implied involving three expert opinions in the field of music education, evaluation, and analysis. This stage presupposed using a rating scale from 1 to 5 for the test questions (less suitable—very suitable). The experts were also asked to write short explanations for the items they considered inappropriate, indicating the reasons. According to the experts, a 20-item test has three dimensions of content validity. These dimensions are piano education, harmony, and music forms. This assessment involved the use of a scoring system of 1 and 0. According to the scale, the lowest score a student could receive was 0 and the highest was 20. This study also implied conducting an analysis of the reliability and validity of the proposed test. The analysis showed that the values of the complexity of points (pj) were in the range of 0.13–0.78, and the values of the discrimination of points (rjx) varied from 0.34 to 0.72. The discrimination index occupies an important place, especially in achievement tests. These results demonstrate that all the points of the piano achievement test have a high discrimination value. The total value of the 20-question achievement test in piano education is 0.86, which indicates the high reliability of the test. In developing the test, scientific works on musical theory were used (Desbruslais, 2018; Spieker, 2016). The piano theory test, or the piano achievement test, can be found in Appendix A.

The researchers have also adapted an observation form developed by Pirgon for piano lessons (Pirgon, 2013) for this study to measure the piano skills of students in both experimental and control groups. This observation form complied with the criteria of the selected works. Accordingly, in the present study, this form consisted of seven criteria, namely, performing a play: with a clear sound, in the right rhythm, with the correct position of the fingers, without a coherence problem, at the right pace, using the legato technique, and using both hands in coordination. The evaluation of the observation form implied using a Likert scale. If the student fulfilled the relevant criterion, he received 5 points, and if he did it very poorly, he received only 1 point. The present research presupposed analyzing the average values, standard deviations, and test correlations (Item-Total) for all points of the observation form of the piano lesson. This analysis showed that the average values of the observation form were in the range of 1.98 to 3.25. In addition, it is worth noting that all points on the scale had a "point-test" correlation of more than 0.40. It indicates that all the points of the observation form correspond to the results of the course. Moreover, Cronbach's alpha was 0.88. It shows that the observation form of the piano course has a high-reliability coefficient.

3.4 Data analysis

The data collection involved using tests of achievements and piano skills. The Shapiro–Wilk normality test facilitated determining that the data obtained had a normal distribution ($p < 0.05$). Therefore, this study implied using an independent sample t-test to compare the results of tests of achievements and piano in both study groups.

Data analysis required the usage of the SPSS 25.0 (Statistical Package for the Social Sciences).

3.5 Ethical issues

The present study presupposed elaborating the course strategy and its further professional conduction. Subsequently, the university administration approved it. This research complies with all the ethical standards and conditions.

4 Results

Table 1 presented below shows the test scores received by students in both groups before the intervention.

According to statistical analysis, the value between the total scores of the pre-test test in the two groups was 0.781. The total scores of the pre-test between the study groups had no significant difference before the intervention. Thus, it is possible to conclude that the groups were equal in terms of academic performance in piano lessons before the intervention. Accordingly, Table 2 below shows the results of preliminary testing of students regarding piano skills in both groups.

In addition, the table shows the results of the Mann–Whitney U-test conducted to assess the pre-test piano skills in both groups. According to the analysis, the z-values in all dimensions of the piano skills scale in the two groups were not significant (0.05). The results showed that before the intervention, there was no significant difference between the pre-test assessments of the piano skills in both study groups. Furthermore, Table 3 shows the average values and standard deviation of the scores obtained by the students in the experimental and control groups before and after intervention according to the results of the academic achievement test within the piano lessons.

The results of the post-test in the experimental group (17.48) prevailed over the scores in the control group (13.76). Accordingly, it indicated the effectiveness of the proposed approach to piano teaching using AR technologies and the IoT. Subsequently, Table 4 presents the results of the analysis carried out according to the results of the piano performance test of students of the experimental and control groups.

The Mann–Whitney U-test facilitated determining a z-value (-4.045) between the two groups. This result shows a significant difference in favor of the experimental group regarding

Table 1 Results comparison of the student achievements in both groups within the piano course (pre-test)

Group	N	Mean Rank	Sum of Ranks	Mann–Whitney U test result, Z	p
Experimental	50	12.35	160.00	-.763	0.445
Control	50	14.61	191.00		

Table 2 Pre-test results comparison of the student achievements in both groups within the piano course

Observation criteria	Group	N	Mean Rank	Sum of Ranks	Mann–Whitney U test result, Z	p
C1. Playing a piece with clear sound	Experimental	50	15.28	198.51	-1.37	.244
	Control	50	11.72	152.52		
C2. Playing a piece with the right rhythm	Experimental	50	12.83	167.30	-0.51	.688
	Control	50	14.14	184.03		
C3. Playing a piece with the correct finger position	Experimental	50	12.13	157.52	-1.34	.361
	Control	50	14.89	193.53		
C4. Performing a play without a coherence problem	Experimental	50	11.70	152.54	-.161	.240
	Control	50	15.25	198.51		
C5. Using the legato technique in the play	Experimental	50	13.80	179.54	-0.23	.843
	Control	50	13.18	171.51		
C6. Using both hands in coordination	Experimental	50	14.20	185.01	-0.58	.651
	Control	50	12.78	166.21		
C7. Playing a piece at the right pace	Experimental	50	11.80	153.51	-1.23	.265
	Control	50	15.17	197.57		
Total	Experimental	50	12.37	161.10	-.073	.478
	Control	50	14.61	190.01		

Table 3 Descriptive analysis of academic performance results in both groups before and after intervention

	Group	N	Mean	Std. Deviation
Pre-Test	Experimental	50	9.78	1.91
	Control	50	10.32	1.30
Post-Test	Experimental	50	17.48	0.98
	Control	50	13.76	2.02

Table 4 Results comparison of the student achievements in both groups within the piano course (post-test)

Group	N	Mean Rank	Sum of Ranks	Mann–Whitney U test result, Z	p
Experimental	50	19.51	253.54	-4.045	0.000
Control	50	7.53	97.49		

*p < 0.05

post-test scores for learning piano playing. The students in the experimental group, who used AR and IoT technologies, received significantly higher average scores compared to the control group. Ultimately, Table 5 shows the results of the piano skills retention test performed using the Mann–Whitney U method.

The analysis showed that there were significant differences only between the two groups in the average indicators of piano playing skills in relation to the total number of points on the retention test ($z = -2.11$; $p = 0.038$). However, the average scores on the criteria of the scale had no significant differences.

5 Discussion

One of the most important factors to consider when designing music education programs using digital technology is the inclusion of applications that facilitate daily practice (Santini, 2020). Regular daily practice is another key determinant of piano performance, as evidenced by the level of musical performance (Bai, 2021). Permanent training of students in the AR experimental group is higher than that of control group students during piano lessons. AR and IoT provide a high level of continuous learning through creating the multimedia learning process, the provision of opportunities for individual differences, and the possibility of customization at each point of the software (Robb et al., 2015). Other researchers have also confirmed the positive impact of AR and IoT on piano learning (Li, 2018). For example, the principle of designing a piano teaching system based on AR technology was presented. These researchers have developed a piano learning system under this principle. Furthermore, this system has been applied in real piano learning (Li, 2018). Subsequently, they collected feedback from students to help improve the efficiency of the developed system. The results showed that most students were satisfied with the training experiment and believed that they had made great progress compared

Table 5 Results comparison of the student achievements regarding piano skills retention in both groups

Observation criteria	Group	N	Mean Rank	Sum of Ranks	Mann–Whitney U test result, Z	p
C1. Playing a piece with clear sound	Experimental	50	14.90	194.01	-1.07	.34
	Control	50	12.07	157.04		
C2. Playing a piece with the right rhythm	Experimental	50	14.45	187.00	-0.73	.53
	Control	50	12.53	164.00		
C3. Playing a piece with the correct finger position	Experimental	50	14.41	187.52	-.082	.53
	Control	50	12.55	163.54		
C4. Performing a play without a coherence problem	Experimental	50	14.83	192.00	-.1.14	.38
	Control	50	12.13	159.00		
C5. Using the legato technique in the play	Experimental	50	15.18	197.49	-1.30	.27
	Control	50	11.80	153.51		
C6. Using both hands in coordination	Experimental	50	15.67	203.00	-1.64	.13
	Control	50	11.82	148.00		
C7. Playing a piece at the right pace	Experimental	50	14.97	194.55	-1.03	.35
	Control	50	12.03	156.52		
Total	Experimental	50	16.61	217.00	-2.11*	.038
	Control	50	10.37	134.00		

to studying under the previous training mode. Some students stated that teaching could be livelier. Another study examines the ARPiano application. This system uses Microsoft Hololens as a complement to a physical MIDI keyboard to facilitate visual learning, understanding, and digitalization of music (Trujano et al., 2018). This new program combines existing peripherals such as a MIDI keyboard and a multifunction pen with AR technology. ARPiano allows users to track the position of each key on the keyboard to display a different spray and annotation on the physical keyboard depending on what the user is playing. On average, study participants performed better when using ARPiano. In addition, they noted the convenience of having the notes go to the corresponding physical key rather than the virtual keyboard on the monitor. Another research describes the development and implementation of an instrument for learning to play the piano with AR technology that uses Microsoft HoloLens and an electric piano with MIDI-over-Bluetooth support (Das et al., 2017). The instrument presents a unique visual interface—a "mirror keyboard overlay" approach adapted to the AR environment and opens up the possibility of learning using this tool. Users at the piano participate in interactive lessons, watch the demonstration of virtual hands, see and hear examples of improvisations, and play their own solos and accompaniment together with AR-designed virtual musicians. This instrument was effective in teaching basic musical concepts. Another study investigated a recently developed AR piano tutor. This tool aims to increase the effectiveness of self-study lessons for beginners (Rigby et al., 2020). This solution is based on the principle of constant feedback and reduced indirectness between the instrument, instructions, and feedback. This allows users to quickly learn to read and understand piano notes without requiring a personal instructor, while maintaining compatibility with traditional instruction. An evaluation of the solution through a study with 22 participants showed that the tool significantly improved motivation and ability to read notes on the piano among students. Another study also proposed a system of support for piano teaching using AR technology (Cai et al., 2019). This system consists of several key functions: 1) pressing needed keys in real time, 2) virtual hand models, and 3) matching instructions between notes and the keyboard. The system has increased students' interest in learning to play the piano by enhancing the learning experience through AR technology. Some researchers have described the development and implementation of a new AR application called FunPianoAR, which aims to activate user interest and improve the piano learning experience (Zeng et al., 2019). FunPianoAR with a user-friendly interface considers a pair game to further reduce the difficulty of playing the piano for adult beginners. In a pair game, one user plays a melody, and the other plays harmony. The researchers conducted an evaluation to compare the effects of two types of AR superimposed information, i.e., an instantaneous method without prompts for the next note to be played, and FunPianoAR with prompts for the next notes to be played. They collected the data on the percentage of correctness and the time difference between the notes that two players should play at the same time. According to the evaluation results, FunPianoAR shows more advantages compared to the instant method. Other researchers studied the prototypes of games for learning to play the piano called KeynVision (Birhanu & Rank, 2017). This system uses Microsoft Hololens to playfully introduce beginners to octave scales, chords, and arpeggios. Based on the results, the augmented mixed reality contextualization can be an effective tool to help students learn piano.

The study sample was limited to a relatively small number of 100 participants. Another limiting factor is the time scope of the training, which is only 20 h. The availability of technical devices required by the participants to install the application is also a limiting factor of this research. In future studies, it is recommended that the sample size be expanded, and that diversity be ensured by including students from different universities and different age groups. It is also suggested that the study time and duration of the experiment be increased. In educational practice, the use of AR and IoT tools is recommended, as it has been shown that they can help students both in the perception of theoretical material and in the achievement of practical skills.

6 Conclusions

The present research focused on studying the influence of implementing and practicing AR and the IoT on piano skills and continuous learning within piano lessons. For this purpose, it presupposed using an experimental approach. The study results demonstrated that the students in the experimental group achieved higher learning outcomes than the students in the control group.

This study revealed significant results comparing the influence of AR and IoT on the traditional curriculum used in piano lessons regarding piano skills. The learning outcomes of students in the experimental (17.48) and control (13.76) groups had significant differences. Using AR and IoT methods and their further application in the teaching process throughout piano learning makes the learning process more efficient. Thus, the teacher can conduct effective and efficient piano teaching using AR and IoT technologies. The results of the present study show that learning to play the piano using AR and the IoT in particular and music education, in general, is more effective than traditional learning. Hence, it is necessary to expand the use of digital music education tools in music educational institutions. In addition, this learning mode requires providing relevant conditions for using innovative technologies. Consequently, it is recommended to ensure the use of music programs and software during computer-enabled lessons in educational institutions in addition to learning to play instruments, such as listening-reading-writing, harmony, accompaniment, and learning to play the electronic organ, orchestral /chamber music.

The research results may contribute to the creation and implementation of modern piano training courses. These instruments will provide students with high-quality technical support for piano training. The research results can be useful to design and implement modern piano training courses. Thanks to the advantages that AR and IoT technologies offer when shaping interactive learning environments, the application of the present findings goes beyond music education and has the potential to boot learning in other specialties.

Future research should focus on designing and developing AR-assisted learning tools and resources. In addition, researchers should expand the study sample.

Appendix A

Piano theory test

1. Types of polyphony.
2. The concept of imitative polyphony.
3. Methods for creating polyphonic texture.
4. Key stages in polyphonic music development.
5. The specifics of sound production and intonation in cantilena.
6. Ways to achieve a high-quality virtuoso performance.
7. Means of musical expression: dynamics, accent, pedalization, and articulation.
8. Phrasing as an artistic and semantic division of the musical language.
9. Things to consider when learning and playing large-form piano pieces (sonata/concert/variations).
10. Sonata, concert and variation forms and their performance interpretation.
11. The concept of individual performing style.
12. Fingering, playing with both hands, the freedom of the performing apparatus, the interplay of artistic and technical skills.
13. The vision of the piano pieces, its development and embodiment during rehearsals and performance.
14. An objective meaning of the piano piece and its subjective interpretation; compliance with the composer's intention, cultural and historical contexts, genre and style requirements, and the principles of musical dramaturgy.
15. The interpretation of music pieces written for an ensemble.
16. A creative approach to performance as an indicator of high musical culture.
17. How musicians improve their artistic taste and develop individual performing styles.
18. Interpretation of the piano score.
19. Modeling and practical implementation of one's own vision for the piano performance in accordance with the genre, style and artistic characteristics of the music piece.
20. Musical dramaturgy of a large-form piano piece.

Data availability Data will be available on request.

Declarations

Conflict of interests Authors declare that they have no conflict of interests.

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