

Internet and VR-Based Model for Piano Teaching: Possibilities of Integration into Higher Education

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Abstract

The study of new approaches to piano instruction highlights the potential for integrating modern technologies into music education. The aim of this research was to identify opportunities and prospects for integrating a VR/Internet-based model of piano learning into China's higher education system and to evaluate its effectiveness. Testing, interviews and expert evaluations were employed to achieve this goal. A total of 150 Chinese students participated in the study, and they were divided into two groups: an experimental group (trained using the developed model) and a control group (trained using traditional methods). The results demonstrated that students in the experimental group achieved significant improvements across all key indicators – piano technique, musicality, music theory and sight-reading – compared with the control group. Specifically, the average improvement in piano technique was 6.62 points, compared to 2.92 in the control group; in musicality, 6.15 points, compared to 3.18; in sight-reading, 7.09 points, compared to 4.10; and in music theory, 5.11 points, compared to 2.56.

Keywords: *innovative learning; instrumental performance; music; piano; virtual reality*

Introduction

Since 2020, the development of virtual reality (VR) technologies and online communication tools during the pandemic has had a profound impact on education, which opened new opportunities for personalized, interactive and remote learning (Kuna et al., 2023). The EdTech industry continues to demonstrate steady growth by integrating artificial intelligence, cloud services and VR technologies into educational

processes, thereby creating adaptive learning environments tailored to individual student needs (Shah et al., 2024).

Conventional music education in higher institutions adheres to an outdated instructional model that limits student engagement and hinders learning personalization (Han et al., 2025). The traditional piano training system – based on individual or group in-person lessons with a teacher, focused on repertoire analysis, technical exercises, sight-reading and music theory without the integration of innovative tools – faces persistent challenges. These include the high cost of individual lessons, limited access to resources (such as quality instruments, performance spaces and qualified teachers), and the necessity to adapt learning pace and content to students' individual needs (Han, 2022).

Narrowing the research focus to the context of higher education appears especially relevant, as contemporary universities and conservatories require innovative educational models capable not only of attracting talented students but also of retaining them by fostering high levels of motivation and engagement (Barytska et al., 2025; Ng et al., 2022). In the context of global digitalization and growing competition for student enrollment, the implementation of VR/Internet-oriented solutions may serve as a critical tool for enhancing the quality and attractiveness of higher education programs (Bylica & Bauman, 2022; Zhang, 2025).

The use of virtual reality in music education enhances students' motivation and is positively associated with their academic performance, thereby creating opportunities for the development of more effective educational programs (Barytska et al., 2025; Li et al., 2025). For instance, a Chinese study demonstrated a positive moderate correlation between the level of motivation and academic achievement (Wu & Tao, 2022; Li & Sun, 2023).

Literature review

With the growing integration of virtual reality (VR) technologies into education, their functions open new possibilities for enhancing music learning in colleges and universities (Han et al., 2025). Digital learning methods improve academic achievement by delivering instruction through online platforms and VR environments (Li et al., 2025). For example, a study conducted in China reported that 72.2 % of students considered the implementation of a VR-based course to be effective (Xiao, 2022).

Digital tools expand access to education and allow students to allocate their practice time better (Feng, 2023; Yan, 2019). Nonetheless, technical constraints persist: transmission delays and limited sound quality hinder synchronous ensemble performance and the accurate evaluation of subtle expressive nuances (Sui & Zhu, 2024). In this regard, asynchronous resources – such as interactive exercises, performance analysis and video feedback – have proven useful for training specific skills, including rhythm, score reading, music theory and aural analysis (Han, 2022). Research on keyboard instruments demonstrates the advantages of VR at the early stages of learning: students acquire spatial orientation on the keyboard more quickly, improve rhythmic

accuracy and exhibit reduced performance anxiety when rehearsing in immersive stage environments (Barytska et al., 2025; Yan & Xia, 2024).

As a pedagogical strategy in music education, gamification enhances student motivation and regular practice (Carrión Candel & Colmenero, 2022). Game-based mechanics such as levels, tasks, feedback and rankings help sustain attention and extend the time devoted to independent rehearsal. The integration of audiovisual tools and gamification elements into music literacy instruction makes the learning process more engaging and fosters improved note-reading skills (Samat et al., 2022; Han et al., 2025; Sui & Zhu, 2024).

Digital learning with online platforms and VR has shown measurable improvements in piano instruction, which confirms the effectiveness of integrated interactive approaches (Li et al., 2025). For instance, an intelligent interactive model of music learning, combining VR with deep learning algorithms, provides highly accurate audio and visual content generation, rapid system response and seamless interaction, which thereby enhances the quality and efficiency of students' musical training (Han et al., 2025). Furthermore, the integration of VR with 6G technologies in music education enables high-precision audio processing, further expanding the possibilities of interactive learning (Sui & Zhu, 2024). By combining the strengths of convolutional and recurrent neural networks, VR can also identify learning patterns, increase the accuracy of performance assessment and demonstrate improvements in musicianship, theoretical understanding and motivation, compared to traditional methods (Sun, 2024).

Well-designed immersive environments have been shown to stimulate learners' attention and engagement, enhance the sense of "presence" and improve the acquisition of procedural and motor skills (Abdallah & Alkaabi, 2023; Venkatesan & Wang, 2023; Zhang, 2025). At the same time, it is important to recognize the limitations of VR: increased cognitive load as well as practical barriers to implementation such as high costs, equipment requirements and challenges in ensuring high-quality sound and haptic feedback (Hamad & Jia, 2022; Matome & Jantjies, 2021). Nevertheless, compared to traditional instructional methods, VR technologies have been found to enhance learning efficiency and teaching performance, stimulate student interest and contribute to the digital transformation and advancement of music education, thereby underscoring the relevance of their integration (Zhang & Yang, 2024).

Problem statement

The purpose of this research was to explore the opportunities and prospects for integrating a VR/Internet-based model of piano instruction into the higher education system and to evaluate its effectiveness in piano training.

Research objectives

1. To design and implement a VR/interactive model of piano instruction in the context of Chinese higher education.

2. To compare the effectiveness of the VR model and traditional methods of teaching in terms of piano technique, musicality, theoretical knowledge and sight-reading skills.
3. To assess the influence of various factors on the learning outcomes of Chinese students.
4. To identify the advantages and limitations of the VR model in order to refine and further improve instructional methodology.

Methodology

Study design

The study was a quasi-experiment with two groups: an experimental group that received instruction through a VR/interactive model and a control group that received traditional instruction. Quantitative data were collected through testing. The test consisted of 15 multiple-choice questions designed to assess knowledge of music theory, including musical symbols, terminology, intervals, chords, forms, composers and tempo markings. Qualitative data were obtained through semi-structured interviews conducted by the researcher, which included five questions focusing on the perceived usefulness of VR-based instruction, encountered challenges, equipment usability, student motivation and the perception of audio/video quality. Responses were recorded for subsequent analysis.

Participants

The study involved 150 undergraduate students majoring in Piano within the program of Musical Performance at higher music institutions in China: Sichuan Conservatory of Music and Xinghai Conservatory of Music. Participants were recruited from the first- and second-year cohorts, as these stages are critical for the development of foundational performance skills, and the integration of innovative technologies may have a substantial impact on the learning process. The mean age of the participants was 19.3 years. The sample consisted of 66 male and 84 female undergraduate students (Table 1).

Table 1
Demographic data and distribution of participants by group

University	Course	Experimental group		Control group	
		Male	Female	Male	Female
Sichuan Conservatory	1	9	10	8	11
	2	8	10	8	10
Xinghai Conservatory	1	9	11	8	12
	2	8	10	8	10
Total	1.2	34	41	32	43
			75		75

Participant recruitment was conducted on a voluntary basis through informational announcements posted in academic buildings and on the official websites of the

conservatories. The inclusion criteria required participants to possess basic piano-playing skills, confirmed by the results of entrance examinations, and no prior experience with VR technologies in music education. Exclusion criteria included significant visual or motor impairments that could hinder the use of VR equipment, prior experience with VR technologies and unwillingness to participate.

Research tools

Piano Technique – Piano performance technique was assessed according to fluency, accuracy, rhythmic stability and motor coordination. Each parameter was rated on a 5-point scale (1 = low level, 5 = high level), with a maximum total score of 20. For this assessment, students performed course-based musical excerpts of moderate difficulty, including etudes and short pieces selected by instructors to match participants' proficiency levels. Examples of repertoire included Etude No. 2 from Etudes Faciles by C. Burns, Prelude No. 1 from Twelve Preludes by F. Kuhlau, and Sonatina in C Major, Op. 36 No. 1 by M. Clementi. Evaluation criteria encompassed accuracy of notation, intonation clarity, rhythmic and tempo precision, and coordination of both hands. Each excerpt was performed within a time frame of 3–5 minutes.

Musicality – Musicality was assessed on the basis of expressiveness, phrasing, dynamics and tempo. Rating sheets included 5-point scales for each criterion, allowing for the quantification of musicality.

Music Theory Knowledge – Theoretical knowledge was assessed through a custom-designed test comprising 15 multiple-choice questions covering topics such as notation, harmony, musical forms and music history. Content validity was ensured by an expert panel consisting of three instructors in music theory, each with more than ten years of teaching experience. All fifteen items were evaluated for their alignment with the stated assessment objectives, thereby reducing the risk of a mismatch between the test content and the construct being measured.

Pilot testing was conducted with a separate subsample of 20 students who did not participate in the main experiment, which eliminated the possibility of a retesting effect. Cronbach's α reached 0.79, which indicated acceptable internal consistency – an adequate level for a fifteen-item instrument (Field, 2018). At the same time, the coefficient approached the lower boundary of what is commonly considered "good" reliability (0.80); therefore, expanding the item pool could further strengthen the psychometric properties of the test.

Item difficulty indices ($p = 0.35\text{--}0.72$) fell within the optimal range: no ceiling effects were observed for any item, and the instrument did not contain excessively difficult tasks. The test duration ranged from 20 to 35 minutes. Each correct answer received 1 point, while incorrect or missing answers received 0 points, with a maximum possible score of 15. The full version of the test is provided in Appendix 1.

Sight-Reading – Sight-reading ability was tested by requiring students to perform two unfamiliar excerpts (8-12 measures each) at the tempo indicated in the score. Exercises

were selected in keys with up to two accidentals and contained moderate rhythmic challenges. Assessment criteria included fluency, accuracy of score realization and rhythmic/tempo stability, each rated on a 5-point scale, with a maximum total score of 20. Students were allotted up to 10 minutes to complete the sight-reading tasks. Examples included: (1) a fragment from *Album for the Young* by R. Schumann, piece *Melody* (C major, 4/4), designed to test basic fluency and intonation accuracy; (2) a fragment from *Mikrokosmos* by B. Bartók, No. 48 *In Bulgarian Rhythm* (simplified version), designed to assess rhythmic and tempo stability.

Interviews – In addition, 30 participants from the experimental group were randomly selected for interviews to capture subjective impressions of using the VR/Internet-based instructional model (Appendix 2). The interview sample consisted primarily of highly engaged students, introducing a potential selection bias that may have inflated the perceived level of satisfaction with the platform. Interviews were conducted individually in person and lasted up to 10 minutes.

Expert Evaluation – All assessments were conducted by qualified piano faculty from both conservatories, who served as independent evaluators with professional expertise in music education and pedagogy. To verify inter-rater reliability across the domains of piano technique, musicality, sight-reading and music theory, Cronbach's α coefficients were calculated, yielding values of 0.87, 0.85, 0.84, and 0.83, respectively, indicating high internal consistency of the rating scales.

Research procedure

The experiment lasted 12 weeks (3 months) and included the following stages: an introductory briefing and pre-test, the main instructional program (two sessions per week, each lasting 90 minutes), and a final post-test. The pre-test was administered on the final working day of the introductory week at the participating universities. Each participant completed four assessment blocks within a single session lasting up to 60 minutes: (1) technical performance, (2) musicality, (3) music theory test and (4) sight-reading.

The experimental group received instruction in university classrooms equipped with VR systems (VR headset with controllers), digital keyboards with MIDI output and a local area network. The software package consisted of several components: a Unity-based application running in the VR headset for student practice, a university cloud server for storing session data and performance results, an Instructor Dashboard – a web portal for faculty to monitor student progress, and the Moodle learning management system (LMS), which was used for hosting theoretical materials and tests. In addition, Zoom was employed for online master classes and real-time communication. Figure 1 presents an overview of the instructional system. The hardware configuration was based on Meta Quest 2 headsets, featuring a resolution of 1832×1920 pixels per eye, a 90 Hz refresh rate, and a 97° field of view – parameters that enabled detailed visualization of both the musical staff and the keyboard. Motion-to-photon latency did

not exceed 20 ms, a threshold above which users typically begin to perceive noticeable desynchronization. A Yamaha P-45 digital piano was also employed, allowing system latency to be measured at approximately 5 ms, thereby effectively eliminating audible delay in sound reproduction. The software environment was built on Unity 2021.3 LTS in combination with the DryWetMIDI library for MIDI processing.

Audio was sampled at 48 kHz, the standard for professional audio production. Spatial sound localization was implemented using the Steam Audio library, which enabled participants to perceive the sound source as originating directly from the instrument rather than from the headphones. The server infrastructure was deployed on a system equipped with an Intel Xeon E5-2680 v4 processor, 64 GB of RAM, and a gigabit network channel. This configuration was designed to process data streams from all 75 participants in the experimental subsample simultaneously without noticeable degradation in system responsiveness.

The data pipeline – from the VR headset to the university server and subsequently to the instructor dashboard – was designed to remain transparent and traceable. Data streams passed through several components, including the VR client, the university server, the LMS Moodle environment and the instructor interface. At each stage, aggregated records were supplemented with metrics of performance accuracy and timing.

Performance accuracy was evaluated in real time: for each played note, the normalized temporal deviation was automatically calculated as $\Delta = |t_{\text{actual}} - t_{\text{reference}}| / t_{\text{reference}}$. This dimensionless scale enabled comparisons of performances recorded at different reference tempos and standardized errors across sessions. Each session automatically generated a JSON log, which was stored in a PostgreSQL database. The source code and technical documentation are available upon request, ensuring the possibility of reproducing the described pipeline by independent research teams.

Before the intervention, participants received a safety briefing and equipment check. They were advised to discontinue sessions immediately if any signs of discomfort occurred.

Each 90-minute VR session was structured as follows:

1. Introductory warm-up and equipment setup (5 minutes)
2. Technical practice including exercises, etudes and illuminated key training (25 minutes)
3. Repertoire study with video lessons and playback on the virtual keyboard (30 minutes)
4. Sight-reading and improvisation or creative tasks (15 minutes)
5. Feedback and assignment of homework within the LMS (15 minutes)

During the VR sessions, the application captured MIDI and audio data in real time, analyzed pitch and rhythmic accuracy, calculated bar-by-bar precision, detected errors and generated short recommendations. All sessions were automatically recorded (audio, MIDI and first-person VR video), with logs uploaded to the server and displayed in the



Figure 1. Music learning system

Instructor Dashboard. Recorded metrics included practice time, performance accuracy, error statistics and additional indicators collected from both the VR application and the LMS. Asynchronous video lessons (3–8 minutes each) were available in VR and via the LMS. To minimize discomfort, mandatory 2-minute breaks were scheduled every 20 minutes, and participants received detailed safety instructions.

The control group followed the same curriculum in terms of content and duration (two sessions of 90 minutes per week), but in a traditional format with face-to-face piano instruction. The lesson structure was parallel to the experimental group:

1. Introductory warm-up (5 minutes)
2. Technical practice guided by the teacher, including demonstration and correction of posture and hand positioning (25 minutes)
3. Repertoire study with analysis, joint performance and corrective feedback (30 minutes)
4. Sight-reading and improvisation (15 minutes)
5. Feedback and assignment of homework (15 minutes)

Home practice was standardized across both groups. All students were recommended to practice 30 minutes per day outside of scheduled sessions. In addition, the experimental group was encouraged to complete 20–30 minutes of independent VR-based practice three times per week, focusing on repetition of lessons and technical exercises. The

inequality in time allocation was documented in the limitations section: participants in the experimental subsample received an additional 60-90 minutes of VR-based training each week. Under the current study design, it is difficult to disentangle the contribution of the increased volume of practice from the specific pedagogical effect of the VR technology itself. The VR platform automatically logged usage data (time spent in the application, number of exercise repetitions and video views), while the control group maintained electronic practice journals and uploaded recordings to the LMS. Access times and material usage were tracked automatically.

Assessment procedures included a midterm and a final evaluation. The midterm test, conducted in week 6, included a short technical performance task (one excerpt) and verification of home practice activity. Final testing, conducted in week 12, replicated the pre-test design and included the same repertoire excerpts, identical theory tests and two new sight-reading fragments.

Data analysis

All statistical analyses were performed using SPSS software, version 26. To assess the normality of data distribution, the Shapiro–Wilk test was applied. Accordingly, Pearson’s correlation analysis was used for normally distributed parameters, while Spearman’s non-parametric correlation analysis was applied to data that did not meet the normality assumption. Group comparisons were conducted using Student’s t-test for normally distributed data and the Mann–Whitney U test for data that were not distributed normally. Analysis of variance (ANOVA) was employed to examine differences between the experimental and control groups across multiple parameters simultaneously, as well as to assess the effects of the “year” and “group” factors on learning outcomes. Prior to conducting the two-way ANOVA, the assumption of homogeneity of variances across the four cells of the factorial design (experimental × Year 1, experimental × Year 2, control × Year 1, control × Year 2) was tested using Levene’s test. A two-way factorial ANOVA (2 × 2) was conducted using Type III sums of squares (Type III SS), whereby each effect was evaluated after controlling for all other effects in the model. This procedure ensures correct interpretation of main effects and interactions in unbalanced designs, as each estimate is assessed conditionally on the remaining model terms (Maxwell & Delaney, 2004). Additionally, a method for analyzing the temporal accuracy of note execution was implemented. Qualitative interview data were analyzed using content analysis.

Ethical considerations

The study adhered to fundamental ethical principles, including voluntary participation, informed consent and the confidentiality of participant data (Drolet et al., 2023). All students were informed in advance about the purpose of the study, the methods of data collection and their right to withdraw at any time without negative consequences. Interview transcripts and assessment results were used only in an aggregated form,

and no personal information was disclosed. Interview files were anonymized with coded identifiers, uploaded to the university server and shared with experts for blind independent evaluation. Written consent for video recording and data processing was obtained from each participant as part of the informed consent procedure.

Limitations

Several limitations should be acknowledged. With a sample of 150 students drawn from two conservatories, the scope for generalization remained limited, and the conclusions are therefore closely tied to a specific cultural and educational context. A further concern lies in the fact that both institutions represented a similar pedagogical profile; the high degree of similarity between their curricula further weakened external validity.

Results

Table 2 presents the comparative dynamics of four key indicators (technique, musicality, theory and sight-reading) in the experimental and control groups before and after the course. The results demonstrate that the experimental group achieved substantially greater improvements across all measures compared with the control group. For piano technique, the mean score increased from 11.24 to 17.86 (gain = 6.62, $t = 14.52$, $p < 0.001$, $d = 2.11$), whereas in the control group it increased from 11.11 to 14.03 (gain = 2.92, $t = 8.03$, $p < 0.001$, $d = 1.17$).

Table 2
Dynamics of music training indicators in the experimental and control groups before and after instruction

Indicator	Group	Before Instruction M (SD)	After Instruction M (SD)	ΔM	t / U	p	d / r
Piano Technique	Experimental	11.24 (2.15)	17.86 (1.42)	+6.62	$t = 14.52$	< 0.001	$d = 2.11$
	Control	11.11 (2.07)	14.03 (1.85)	+2.92	$t = 8.03$	< 0.001	$d = 1.17$
Musicality	Experimental	10.87 (2.34)	17.02 (1.55)	+6.15	$t = 12.94$	< 0.001	$d = 1.88$
	Control	10.73 (2.28)	13.91 (1.97)	+3.18	$t = 7.12$	< 0.001	$d = 1.04$
Music Theory	Experimental	7.82 (2.11)	12.93 (1.02)	+5.11	$U = 421.0$	< 0.001	$r = 0.78$
	Control	7.76 (2.07)	10.32 (1.68)	+2.56	$U = 617.5$	< 0.001	$r = 0.61$
Sight-Reading	Experimental	9.12 (2.44)	16.21 (1.33)	+7.09	$U = 389.0$	< 0.001	$r = 0.81$
	Control	9.05 (2.38)	13.15 (1.82)	+4.10	$U = 598.0$	< 0.001	$r = 0.65$

Note: For parameters with normal distribution, paired t-tests were applied (t, d – Cohen's effect size). For parameters not distributed normally, the Mann–Whitney U test was used (U, r – rank correlation coefficient as a measure of effect size).

In music theory knowledge, the experimental group improved from 7.82 to 12.93 (gain = 5.11, $U = 421.0$, $p < 0.001$, $r = 0.78$), while the control group improved from

7.76 to 10.32 (gain = 2.56, $U = 617.5$, $p < 0.001$, $r = 0.61$). The use of note highlighting, synchronous visualization of keyboard and score, tempo control and automatic identification of problematic passages contributed to the greater progress observed.

In all cases, differences were statistically significant at the $p < 0.001$ level. Effect sizes ($d = 1.88$ – 2.11 ; $r = 0.78$ – 0.81) indicate strong practical significance. The larger improvements in the experimental group are explained by a combination of factors, including multimodal feedback, higher frequency of targeted practice, integration of theory and practice, and gamification of the learning process.

Figure 2 illustrates the results of the note timing accuracy analysis, specifically the relative tempo of each note during a sight-reading task performed by one experimental group student using a fragment from R. Schumann's Album for the Young. This chart was extracted from the Instructor Dashboard, which compiles student data from the VR application and LMS. The figure compares the student's performance with the designated tempo ($\text{♩} = 60$) before training (a) and after training (b).

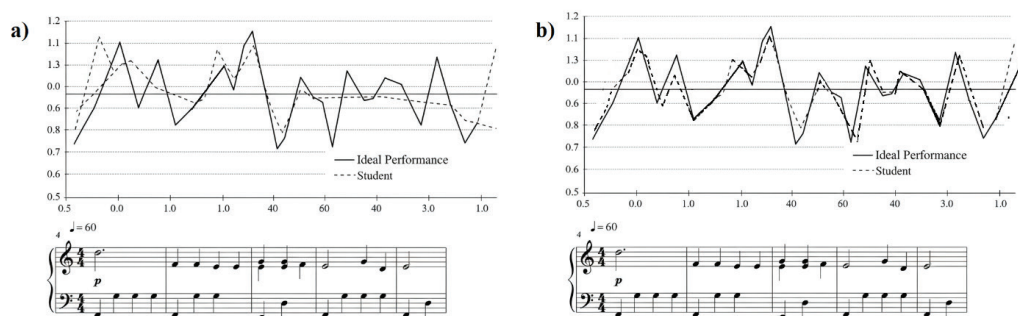


Figure 2. Analysis of the temporal accuracy of playing notes

Figure “a” illustrates that the student’s performance (dotted line) fluctuates considerably around the ideal tempo line ($y = 1.0$). The line frequently shifts upward and downward, indicating unstable rhythm and tempo. This suggests difficulties with fluency and accuracy in reproducing the musical score. Figure “b,” by contrast, demonstrates marked improvement: the student’s performance line is much closer to the ideal line ($y = 1.0$), with smaller and less abrupt deviations. This indicates that the student developed greater control over tempo and rhythm, which can be attributed directly to the instructional intervention.

To examine the effects of the factors “group” (experimental vs. control) and “study year” (first year vs. second year) on learning outcomes, a two-way analysis of variance (Table 3) was conducted. The results revealed that the factor “group” had a statistically significant and substantial effect on piano technique ($F = 124.52$, $p < 0.001$, $\eta^2_{\text{partial}} = 0.63$) and musicality ($F = 110.31$, $p < 0.001$, $\eta^2_{\text{partial}} = 0.60$).

Table 3
Results of the two-way factorial ANOVA (Type III SS) for post-test performance indicators

Indicator	Factor	SS (type III)	df	MS	F	p	η^2_{partial}
Piano Performance Technique	Group	311.30	1	311.30	124.52	< 0.001	0.63
	Year	10.53	1	10.53	4.21	0.043	0.05
	Group × Year	5.08	1	5.08	2.03	0.159	0.03
	Error	365.00	146	2.50	–	–	–
Musicality	Group	308.87	1	308.87	110.31	< 0.001	0.60
	Year	10.75	1	10.75	3.84	0.053	0.04
	Group × Year	3.14	1	3.14	1.12	0.293	0.02
	Error	408.80	146	2.80	–	–	–

Note: Type III sums of squares were applied; all effects were tested after controlling for all other effects in the model. Source: author’s own elaboration.

According to the ANOVA results for piano performance technique, the factor “group” accounted for the largest proportion of variance ($SS = 311.30$, $\eta^2_{\text{partial}} = 0.63$); the mean square exceeded the error term by a factor of 124.52. The factor “year” made a modest contribution to the sum of squares ($SS = 10.53$, $\eta^2_{\text{partial}} = 0.05$) and reached statistical significance at $p = 0.043$: second-year students demonstrated slightly higher post-test results, with their accumulated experience in music education providing a minor performance advantage.

Table 4 presents pairwise comparisons of estimated marginal means (EMMs) with Bonferroni correction. The experimental group significantly outperformed the control group in piano performance technique (mean EMM difference = 3.87, $SE = 0.26$, $p < 0.001$, 95 % CI [3.36, 4.38]) and in musicality (mean EMM difference = 3.15, $SE = 0.27$, $p < 0.001$, 95 % CI [2.62, 3.68]). Differences across years reached significance for technique (mean EMM difference = 0.65, $SE = 0.26$, $p = 0.043$, 95 % CI [0.14, 1.16]), whereas the effect for musicality was not confirmed (mean EMM difference = 0.49, $SE = 0.27$, $p = 0.053$, 95 % CI [-0.04, 1.02]).

Table 4
Estimated marginal means (EMMs) of post-test performance indicators

Indicator	Factor	Level	EMM	SE	95 % CI
Methodology	Group	Experimental	17.88	0.18	[17.52; 18.24]
		Control	14.01	0.18	[13.65; 14.37]
	Year	Year 1	15.62	0.18	[15.26; 15.98]
		Year 2	16.27	0.18	[15.91; 16.63]
Musicality	Group	Experimental	17.04	0.19	[16.66; 17.42]
		Control	13.89	0.19	[13.51; 14.27]
	Year	Year 1	15.22	0.19	[14.84; 15.60]
		Year 2	15.71	0.19	[15.33; 16.09]

Source: author’s own elaboration.

Comparisons across years in the technical domain reached nominal significance ($p = 0.043$): second-year students scored 0.65 points higher than first-year students; the modest gap and small η^2_{partial} (0.05) indicate a genuine, albeit minor, effect of accumulated training. For musicality, the between-year difference of 0.49 points did not meet the $\alpha = 0.05$ criterion ($p = 0.053$), confirming that the decisive factor underlying performance gains was the instructional format itself (Table 5).

Table 5
Estimated marginal means by interaction cells (group \times year)

Group	Year	EMM Technique (SE)	EMM Musicality (SE)
Experimental	1st year	17.52 (0.26)	16.78 (0.27)
Experimental	2 nd year	18.24 (0.26)	17.30 (0.27)
Control	1st year	13.72 (0.26)	13.66 (0.27)
Control	2 nd year	14.30 (0.26)	14.12 (0.27)

Note: EMMs were calculated based on the Type III SS model; pairwise comparisons were adjusted using the Bonferroni method.

Source: author's own elaboration.

Figure 3 provides a visualization of the correlation analysis among the four musical skills: piano technique, musicality, sight-reading and music theory. The graph illustrates the interrelationships between skills in the form of a network, where each skill is represented as a node and the connecting lines indicate the strength of correlations. Line thickness and color denote the degree of association, while Pearson's correlation coefficients are displayed alongside each line to reflect the closeness of the relationships.

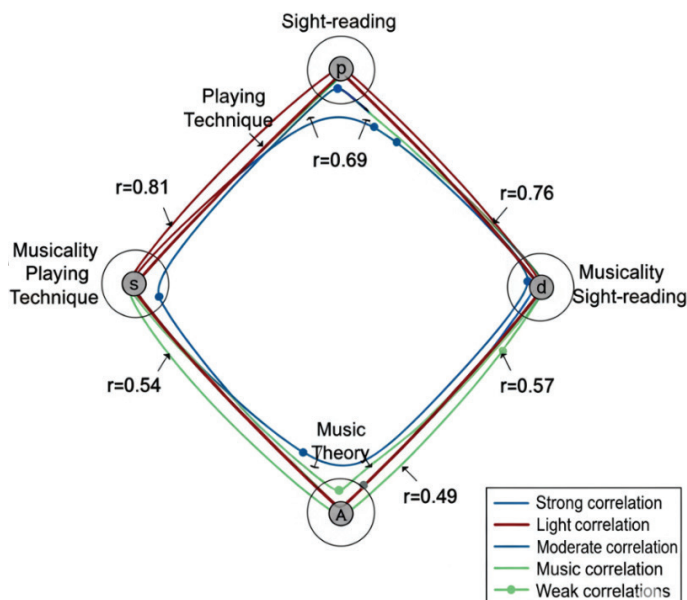


Figure 3. Correlation analysis

The graph indicates that the strongest interrelationships exist among practical performance skills. Piano technique demonstrated strong correlations with both musicality ($r = 0.81$) and sight-reading ($r = 0.76$), which highlighted the mutual influence of motor coordination, execution accuracy and the ability to convey the artistic image of a musical work. Musicality was also strongly associated with sight-reading ($r = 0.69$), which suggests that these skills are highly interdependent: the better a performer reads music, the more freely they can focus on expressiveness, and the greater the precision of their technique. Correlations with music theory were moderate yet statistically significant, with associations identified between theory and technique ($r = 0.54$), sight-reading ($r = 0.57$) and musicality ($r = 0.49$).

The correlations observed between technical proficiency, musicality and sight-reading ability (r ranging from 0.69 to 0.81) suggested the presence of a latent variable – a general musicality factor manifested across all measured dimensions.

Interview analysis further revealed that most participants evaluated the use of the VR/Internet-based learning model positively (Figure 4). The highest responses were linked to usability and strong engagement, reported by 86 % of respondents. Many noted that the immersive experience of VR helped them concentrate on the material and reduced distractions.

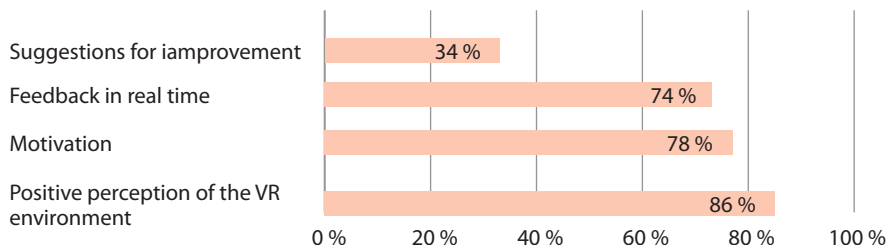


Figure 4. Interview analysis

The motivational aspect proved particularly significant: 78 % of participants reported that gamification elements (points, rewards, rankings) encouraged them to practice more frequently. One student commented, “I started practicing more often because I wanted to surpass my friends in the ranking.” However, some participants noted drawbacks, such as “too many game-based tasks distracted me from serious work on technique.” In addition, 74 % highly valued the real-time feedback features such as illuminated keys and rhythm analysis.

Discussion

The results of the study demonstrate that the integration of a VR/Internet-based model into music instruction significantly enhances the acquisition of core skills compared to traditional methods. The experimental group showed substantial improvements across all indicators: piano technique increased by 6.62 points, musicality by 6.15 points, music theory knowledge by 5.11 points and sight-reading by 7.09 points. While the control

group also showed progress, the gains were smaller: technique (+2.92), musicality (+3.18), theory (+2.56) and sight-reading (+4.10). The marked improvement in musicality in the experimental group can be attributed to distinctive features of VR-based instruction: integrated video demonstrations by instructors, repeated review of phrases, synchronous visual cues for dynamics and phrasing, and the safe immersive environment that reduced performance anxiety and promoted more mindful work on expressiveness. This effect supports the theory of presence, which explains how immersion in VR environments enhances engagement and improves learning outcomes (Triberti et al., 2025). Comparable results were reported by Han et al. (2025) and Li et al. (2025), where the integration of VR and online platforms improved students' academic performance and piano-playing skills. Effect sizes in the range of $d = 1.88-2.11$ were observed. According to the classification proposed by Hattie (2008), values exceeding $d = 1.0$ are considered to represent a "very large" effect. A twofold exceedance of this threshold prompted careful examination for potential methodological artifacts. Five converging factors may have contributed to the inflation of effect sizes. First, participants in the experimental subsample received additional practice time, while the technological novelty of VR may have temporarily increased engagement, forming the first pair of influences. Second, the Hawthorne effect – improved performance resulting from participants' awareness of being observed – together with the generally high intrinsic motivation characteristic of conservatory students, added two further components. Finally, the absence of blind evaluation procedures created conditions under which expert ratings could have been unintentionally inflated. Future experiments will therefore require the implementation of active control conditions and double-blind assessment protocols. Notably, the VR-based music education studies reviewed in the present work did not employ comparable methodological designs.

Conclusion

The results of the study demonstrated that the use of a VR/Internet-based model for piano instruction led to significant improvements across all measured indicators compared to the traditional approach. In the experimental group, a very large effect size was observed for piano technique ($d = 2.11$), underscoring the practical significance of the method. The reduction in standard deviation following instruction (from 2.15 to 1.42) indicated a leveling of participants' performance, which suggests that the platform enabled less-experienced students to close the gap with more advanced peers. The greatest improvements were observed in sight-reading skills ($r = 0.81$) and piano technique, which highlights the considerable impact of the VR/Internet model on the development of practical performance abilities. The factor "group" was significant across all indicators, while the factor "course" was significant only for technique, with a small effect ($\eta^2 = 0.05$); no interaction effects were identified. Correlation analyses revealed strong associations among technique, musicality and sight-reading, with music theory exerting a comparatively weaker influence. Qualitative interview data

further indicated that the VR/Internet model not only enhanced skill acquisition but also increased motivation and satisfaction with learning.

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Model poučavanja klavira utemeljen na internetskim tehnologijama i virtualnoj stvarnosti: mogućnosti njegove integracije u visoko obrazovanje

Sažetak

Istraživanje novih pristupa poučavanja klavira ističe potencijal integracije modernih tehnologija u glazbeno obrazovanje. Cilj ovoga istraživanja bio je identificirati prilike i izgled za integraciju VR/internetskoga modela učenja klavira u kineski visokoobrazovni sustav te procijeniti njegovu učinkovitost. Za postizanje toga cilja korišteni su testovi, intervjui i stručne procjene. U istraživanju je sudjelovalo ukupno 150 kineskih studenata podijeljenih u dvije skupine: eksperimentalnu skupinu (koja je učila koristeći se razvijenim modelom) i kontrolnu skupinu (koja je učila koristeći se tradicionalnim metodama). Rezultati su pokazali da su studenti u eksperimentalnoj skupini postigli značajna poboljšanja u svim ključnim pokazateljima – klavirskoj tehnici, muzikalnosti, teoriji glazbe i čitanju s lista – u usporedbi s kontrolnom skupinom. Konkretno, prosječno poboljšanje u klavirskoj tehnici iznosilo je 6,62 boda, u usporedbi s 2,92 u kontrolnoj skupini; u muzikalnosti 6,15 bodova, u usporedbi s 3,18; u čitanju s lista 7,09 bodova, u usporedbi s 4,10; i u teoriji glazbe 5,11 bodova, u usporedbi s 2,56.

Ključne riječi: inovativno učenje; instrumentalna izvedba; glazba; klavir; virtualna stvarnost

Uvod

Od 2020. godine razvoj tehnologija virtualne stvarnosti (VR) i alata za online komunikaciju tijekom pandemije imao je dubok utjecaj na obrazovanje, što je otvorilo nove mogućnosti za personalizirano, interaktivno učenje i učenje na daljinu (Kuna i sur., 2023). Industrija obrazovne tehnologije nastavlja pokazivati stalan rast putem integriranja umjetne inteligencije, usluga u oblaku i VR tehnologija u obrazovne procese, čime se stvaraju primjerena okružja za učenje prilagođeno individualnim potrebama studenata (Shah i sur., 2024).

Konvencionalno glazbeno obrazovanje na visokim učilištima pridržava se zastarjelog nastavnog modela koji ograničava angažman studenata i ometa personalizaciju učenja

(Han i sur., 2025). Tradicionalni sustav klavirske poduke – temeljen na individualnoj ili grupnoj nastavi uživo s učiteljem, usmjeren na analizu repertoara, tehničke vježbe, čitanje s lista i teoriju glazbe bez integracije inovativnih alata – suočava se s trajnim izazovima. Oni podrazumijevaju visoke troškove individualnih sati, ograničen pristup resursima (kao što su kvalitetni instrumenti, prostori za nastupe i kvalificirani nastavnici) i potrebu prilagodbe tempa i sadržaja učenja individualnim potrebama studenata (Han, 2022).

Sužavanje istraživačkoga fokusa na kontekst visokoga obrazovanja čini se osobito relevantnim jer suvremena sveučilišta i konzervatoriji zahtijevaju inovativne obrazovne modele sposobne ne samo privući talentirane studente, već i zadržati ih poticanjem visokih razina motivacije i angažmana (Barytska i sur., 2025; Ng i sur., 2022). U kontekstu globalne digitalizacije i sve veće konkurencije za upis studenata, primjena VR/internetski orijentiranih rješenja može poslužiti kao ključan alat za poboljšanje kvalitete i privlačnosti visokoškolskih programa (Bylica i Bauman, 2022; Zhang, 2025).

Upotreba virtualne stvarnosti u glazbenom obrazovanju povećava motivaciju studenata i pozitivno je povezana s njihovim akademskim uspjehom, čime se stvaraju mogućnosti za razvoj učinkovitijih obrazovnih programa (Barytska i sur., 2025; Li i sur., 2025). Na primjer, kineska studija pokazala je pozitivnu umjerenu povezanost između razine motivacije i akademskoga uspjeha (Wu i Tao, 2022; Li i Sun, 2023).

Pregled literature

S rastućom integracijom tehnologije virtualne stvarnosti (VR) u obrazovanje otvaraju se nove mogućnosti za poboljšanje učenja glazbe na fakultetima i sveučilištima (Han i sur., 2025.). Digitalne metode učenja poboljšavaju akademski uspjeh putem nastave preko internetskih platformi i VR okružja (Li i dr., 2025.). Na primjer, studija provedena u Kini izvijestila je da je 72,2 % studenata smatralo provedbu tečaja temeljenoga na VR-u učinkovitim (Xiao, 2022.).

Digitalni alati proširuju pristup obrazovanju i omogućuju studentima bolju raspodjelu vremena za vježbanje (Feng, 2023; Yan, 2019). Unatoč tome, tehnička ograničenja i dalje postoje: kašnjenja u prijenosu i ograničena kvaliteta zvuka ometaju sinkrono izvođenje ansambla i točnu procjenu suptilnih ekspresivnih nijansi (Sui i Zhu, 2024). U tom pogledu, asinkroni resursi, kao što su interaktivne vježbe, analiza izvedbe i povratne videoinformacije, pokazali su se korisnima za stjecanje specifičnih vještina koje uključuju ritam, čitanje notnoga zapisa, glazbenu teoriju i slušnu analizu (Han, 2022). Istraživanja o instrumentima s klavijaturom pokazuju prednosti VR-a u ranim fazama učenja: studenti brže steču prostornu orijentaciju na klavijaturi, poboljšavaju ritmičku točnost i pokazuju smanjenu tjeskobu prije nastupa kada vježbaju u VR okružjima koja oponašaju scenske situacije (Barytska i sur., 2025; Yan i Xia, 2024).

Kao pedagoška strategija u glazbenom obrazovanju, gamifikacija poboljšava motivaciju učenika i redovito vježbanje (Carrión Candel i Colmenero, 2022). Razvijanje tehničkih vještina putem igre – poput razina, zadataka, povratnih informacija i ljestvica – pomaže

održati pažnju i produljiti vrijeme posvećeno samostalnom uvježbavanju. Uključivanje audiovizualnih alata i elemenata gamifikacije u nastavu glazbene pismenosti čini proces učenja zanimljivijim i potiče poboljšanje vještina čitanja nota (Samat i sur., 2022.; Han i sur., 2025.; Sui i Zhu, 2024).

Digitalno učenje putem internetskih platformi i VR-om pokazalo je mjerljiva poboljšanja u poučavanju klavira, potvrđujući učinkovitost integriranih interaktivnih pristupa (Li i sur., 2025). Na primjer, inteligentni interaktivni model za učenje glazbe koji kombinira VR s algoritmima dubokoga učenja pruža vrlo preciznu generaciju audio i vizualnoga sadržaja, brzu reakciju sustava i besprijekornu interakciju, čime se poboljšava kvaliteta i učinkovitost glazbenoga obrazovanja učenika (Han i sur., 2025). Nadalje, integracija VR-a s 6G tehnologijama u glazbenome obrazovanju omogućuje obradu zvuka visoke preciznosti, čime se dodatno proširuju mogućnosti interaktivnoga učenja (Sui i Zhu, 2024). Prilikom kombiniranja prednosti konvolucijskih i rekurentnih neuronskih mreža, VR također može prepoznati obrasce učenja, povećati točnost procjene izvedbe i poboljšati sposobnost muziciranja, teorijsko razumijevanje i motivaciju u usporedbi s tradicionalnim metodama (Sun, 2024).

Pokazalo se da dobro dizajnirana virtualna okružja pozitivno utječu na pažnju i angažman studenata, pojačavaju osjećaj „prisutnosti” i poboljšavaju stjecanje proceduralnih i motoričkih vještina (Abdallah i Alkaabi, 2023; Venkatesan i Wang, 2023; Zhang, 2025). Istovremeno je važno prepoznati ograničenja VR-a: povećano kognitivno opterećenje kao i praktične prepreke u primjeni, poput visokih troškova, zahtjeva za opremom i izazova u osiguravanju visokokvalitetnoga zvuka i taktilnih povratnih informacija (Hamad i Jia, 2022; Matome i Jantjies, 2021). Ipak, u usporedbi s tradicionalnim nastavnim metodama, utvrđeno je da VR tehnologije poboljšavaju učinkovitost učenja i nastavne performanse, potiču interes studenata i doprinose digitalnoj transformaciji i napretku glazbenoga obrazovanja, čime se naglašava relevantnost njihove integracije (Zhang i Yang, 2024).

Problem istraživanja

Svrha ovoga istraživanja bila je ispitati mogućnosti i izgled integracije VR/ internetskoga modela poučavanja klavira u sustav visokoga obrazovanja te procijeniti njegovu učinkovitost u nastavi klavira.

Ciljevi istraživanja

1. Izraditi i implementirati VR/interaktivni model poučavanja klavira u kontekstu visokoga obrazovanja u Kini.
2. Usporediti učinkovitost VR modela i tradicionalnih metoda poučavanja u pogledu klavirske tehnike, muzikalnosti, teorijskoga znanja i vještina improvizacije.
3. Procijeniti utjecaj različitih čimbenika na ishode učenja kineskih studenata.
4. Utvrditi prednosti i ograničenja VR modela kako bi se usavršila i dodatno poboljšala metodologija poučavanja.

Metodologija

Dizajn istraživanja

Ovo istraživanje provedeno je kao kvaziekperiment s dvije skupine: eksperimentalnom skupinom, koja je sudjelovala u nastavi putem VR/interaktivnoga modela i kontrolnom skupinom, koja je poučavana tradicionalnim metodama. Kvantitativni podatci prikupljeni su testiranjem. Test se sastojao od 15 pitanja s višestrukim izborom, osmišljenih za procjenu znanja iz glazbene teorije, uključujući glazbene znakove, terminologiju, intervale, akorde, oblike, skladatelje i oznake tempa. Kvalitativni podatci dobiveni su polustrukturiranim intervjuima koje je proveo istraživač, a koji su uključivali pet pitanja usmjerenih na percipiranu korisnost nastave temeljene na VR-u, izazove na koje su naišli, upotrebljivost opreme, motivaciju studenata i percepciju kvalitete zvuka i slike. Odgovori su snimljeni radi naknadne analize.

Sudionici

U istraživanju je sudjelovalo 150 preddiplomskih studenata smjera Klavir u sklopu programa Glazba izvedba na ustanovama visokoga glazbenog obrazovanja u Kini: Sichuan konzervatoriju glazbe i Xinghai konzervatoriju glazbe. Sudionici su u vrijeme istraživanja bili na prvoj i drugoj godini studija jer su te faze ključne za razvoj temeljnih izvedbenih vještina, a integracija inovativnih tehnologija može imati značajan utjecaj na proces učenja. Prosječna dob sudionika bila je 19,3 godine. Uzorak se sastojao od 150 studenata, od koji je 66 bilo muških a 84 ženskih (Tablica 1).

Tablica 1

Odabir sudionika proveden je na dobrovoljnoj osnovi putem informativnih obavijesti objavljenih u akademskim zgradama i na službenim mrežnim stranicama konzervatorija. Kriteriji uključivanja zahtijevali su da sudionici posjeduju osnovne vještine sviranja klavira, potvrđene rezultatima prijemnih ispita te da nemaju prethodnoga iskustva s VR tehnologijama u glazbenom obrazovanju. Kriteriji isključenja obuhvaćali su značajna vizualna ili motorička oštećenja koja bi mogla ometati korištenje VR opreme, prethodno iskustvo s VR tehnologijama i nevoljkost za sudjelovanjem.

Istraživački alati

Tehnika sviranja klavira. Tehnika izvedbe na klaviru ocjenjivana je prema točnosti, točnosti, ritmičkoj stabilnosti i motoričkoj koordinaciji. Svaki je parametar ocijenjen na petostupanjskoj ljestvici (1 = nizak stupanj, 5 = visok stupanj), pri čemu je maksimalni ukupni broj bodova iznosio 20. Za ovu procjenu studenti su izveli glazbene isječke umjerene težine iz nastavnoga gradiva, uključujući etide i kratke skladbe koje su profesori odabrali kako bi odgovarale razini vještine sudionika. Primjeri repertoara uključivali su Etidu br. 2 iz zbirke „Lake etide” C. Burnsa, Preludij br. 1 iz zbirke „Dvanaest preludija” F. Kuhlaua i Sonatinu u C-duru, op. 36 br. 1 M. Clementija. Kriteriji ocjenjivanja obuhvaćali su točnost notacije, jasnoću intonacije, preciznost

ritma i tempa te koordinaciju objiju ruku. Svaki je isječak izveden u vremenskom okviru od tri do pet minuta.

Muzikalnost. Muzikalnost je ocjenjivana na temelju izražajnosti, fraziranja, dinamike i tempa. Obrasci za ocjenjivanje sadržavali su petostupanjsku ljestvicu za svaki kriterij, što je omogućavalo kvantifikaciju muzikalnosti.

Znanje iz teorije glazbe. Teorijsko znanje ocijenjeno je prilagođenim testom koji se sastojao od 15 pitanja s višestrukim izborom, obuhvaćajući teme poput notacije, harmonije, glazbenih oblika i povijesti glazbe. Sadržajna valjanost osigurana je stručnim panelom sastavljenim od troje profesora teorije glazbe s više od deset godina iskustva u poučavanju. Svih petnaest pitanja ocijenjena su prema usklađenosti s navedenim ciljevima procjene, čime je smanjen rizik od nesklada između sadržaja testa i konstrukta koji se mjeri. Pokusno testiranje provedeno je na zasebnom poduzorku od 20 studenata koji nisu sudjelovali u glavnom eksperimentu, čime je eliminirana mogućnost efekta ponovnoga testiranja. Cronbachov α dosegao je 0,79, što ukazuje na prihvatljivu unutarnju dosljednost – adekvatnu razinu za instrument s petnaest stavki (Field, 2018). Istovremeno se koeficijent približio donjoj granici onoga što se općenito smatra „dobrom» pouzdanošću (0,80), stoga bi proširenje skupa stavki moglo dodatno ojačati psihometrijska svojstva testa.

Indeksi težine stavki ($p = 0,35-0,72$) bili su u optimalnom rasponu: ni za jednu stavku nije zabilježen efekt stropa, a instrument nije sadržavao pretjerano teške zadatke. Trajanje testa kretalo se od 20 do 35 minuta. Za svaki točan odgovor dodijeljen je 1 bod, a za netočne ili izostavljene odgovore 0 bodova, pri čemu je maksimalni mogući broj bodova bio 15. Cjelovita verzija testa nalazi se u Prilogu 1.

Čitanje s lista. Sposobnost čitanja s lista testirana je tako što su studenti morali izvesti dva nepoznata ulomka (po 8 – 12 mjera) u tempu naznačenom u partituri. Vježbe su odabrane u tonalitetima s najviše dvije dijakritičke oznake i sadržavale su umjerene ritmičke izazove. Kriteriji ocjenjivanja uključivali su tečnost, točnost izvedbe notnoga zapisa i stabilnost ritma/tempa, pri čemu je svaki ocjenjivan na petostupanjskoj ljestvici, s maksimalnim ukupnim brojem bodova od 20. Studentima je bilo dodijeljeno najviše deset minuta za izvođenje zadataka čitanja s lista. Primjeri su uključivali: (1) fragment iz djela „Album za mladež” R. Schumanna, skladbu „Melodija” (C-dur, 4/4), osmišljenu za provjeru osnovne tečnosti i točnosti intonacije; (2) fragment iz djela „Mikrokozmos” B. Bartóka, br. 48 „U bugarskom ritmu” (pojednostavljena verzija), osmišljen za procjenu stabilnosti ritma i tempa.

Intervjui. Dodatno je 30 sudionika iz eksperimentalne skupine nasumično odabrano za intervju kako bi se prikupili subjektivni dojmovi o korištenju VR/internetskoga modela poduke (Prilog 2). Uzorak ispitanika uglavnom su činili visoko angažirani studenti, što je uvelo potencijalnu pristranost odabira koja je mogla povećati percipiranu razinu zadovoljstva platformom. Intervjui su provedeni pojedinačno, uživo i trajali su do 10 minuta.

Stručna procjena. Sve su procjene proveli kvalificirani profesori klavira iz objiju glazbenih škola, koji su djelovali kao neovisni ocjenjivači s profesionalnim iskustvom

u glazbenome obrazovanju i pedagogiji. Kako bi se provjerila pouzdanost među ocjenjivačima u područjima klavirske tehnike, muzikalnosti, čitanja s lista i teorije glazbe, izračunati su Cronbach α koeficijenti, koji su pokazali vrijednosti od 0,87, 0,85, 0,84 i 0,83, što ukazuje na visoku unutarnju konzistentnost ljestvica ocjenjivanja.

Postupak istraživanja

Eksperiment je trajao 12 tjedana (3 mjeseca) i uključivao je sljedeće faze: uvodno informiranje i preliminarni test, glavni program poduke (dvije sesije tjedno, svaka u trajanju od 90 minuta) i završni test. Predtest je proveden posljednjega radnog dana uvodnoga tjedna na sveučilištima. Svaki je sudionik završio četiri procjene u jednoj sesiji koja je trajala do 60 minuta: (1) tehnička izvedba, (2) muzikalnost, (3) test teorije glazbe i (4) čitanje s lista.

Eksperimentalna skupina poučavana je u sveučilišnim učionicama opremljenim VR sustavima (VR naočale s kontrolerima), digitalnim tipkovnicama s MIDI izlazom i lokalnom mrežom. Softverski paket sastojao se od nekoliko komponenti: aplikacije temeljene na Unityju koja se pokretala na VR naočalama za vježbu studenata; sveučilišnoga *cloud* poslužitelja za pohranu podataka o sesijama i rezultata postignuća; profesorske nadzorne ploče – mrežnoga portala kojim nastavno osoblje prati napredak studenata te sustava za upravljanje učenjem (LMS) Moodle, koji se koristio za objavljivanje teorijskih materijala i ispita. Osim toga, za *online* majstorske tečajeve i komunikaciju u stvarnom vremenu korišten je Zoom. Slika 1. prikazuje pregled nastavnoga sustava. Hardverska konfiguracija temeljila se na VR naočalama Meta Quest 2, koje imaju rezoluciju od 1832×1920 piksela po oku, frekvenciju osvježavanja od 90 Hz i vidno polje od 97° – parametri koji su omogućili detaljnu vizualizaciju glazbene notacije i klavijature. Latencija od pokreta do fotona nije prelazila 20 ms – prag iznad kojeg korisnici obično počinju primjećivati vidljivu neusklađenost. Također je korišten digitalni klavir Yamaha P-45, što je omogućilo mjerenje latencije sustava na otprilike 5 ms, čime su učinkovito eliminirana čujna kašnjenja u reprodukciji zvuka. Softversko okruženje izgrađeno je na Unity 2021.3 LTS u kombinaciji s bibliotekom DryWetMIDI za obradu MIDI-ja.

Audio je uzorkovan pri 48 kHz – standardu za profesionalnu audioprodukciju. Prostorna lokalizacija zvuka implementirana je pomoću Steam Audio biblioteke, omogućujući sudionicima da izvor zvuka percipiraju kao da dolazi izravno iz instrumenta, a ne iz slušalica. Infrastruktura poslužitelja raspoređena je na sustavu opremljenom procesorom Intel Xeon E5-2680 v4, 64 GB RAM-a i gigabitnim mrežnim sučeljem. Ova je konfiguracija osmišljena za istovremenu obradu tokova podataka svih 75 sudionika u eksperimentalnom poduzorku bez primjetnoga pogoršanja prilagodljivosti sustava.

Protok podataka od VR slušalica do sveučilišnoga poslužitelja, a potom do profesorske nadzorne ploče, bio je osmišljen kao transparentan i nadziran. Tokovi podataka prolazili su kroz nekoliko komponenti, uključujući VR, sveučilišni poslužitelj, LMS okruženje Moodle i profesorsko sučelje. Na svakoj su fazi objedinjeni zapisi bili dopunjeni metrikom točnosti izvedbe i vremenskih mjera.

Točnost izvedbe ocjenjivana je u stvarnom vremenu: za svaku odsviranu notu automatski se izračunavala normalizirano vremensko odstupanje $\Delta = |t_{\text{stvarna}} - t_{\text{referenca}}| / t_{\text{referenca}}$. Ova skala bez dimenzija omogućila je usporedbu izvedbi snimljenih pri različitim referentnim tempima i standardizaciju pogrešaka među sesijama. Svaka je sesija automatski generirala JSON zapisnik koji je pohranjen u PostgreSQL bazi podataka. Izvorni kod i tehnička dokumentacija dostupni su na zahtjev, čime se osigurava mogućnost reproduciranja opisanoga procesa neovisnim istraživačkim timovima.

Prije same intervencije sudionici su izviješteni o sigurnosti i provjerena je oprema. Savjetovani su da odmah prekinu sesiju ako dožive bilo kakve znakove nelagode.

Slika 1.

Svaka 90-minutna VR sesija bila je strukturirana na sljedeći način:

1. Uvodno zagrijavanje i postavljanje opreme (5 minuta)
2. Uvježbavanje tehnike koje uključuje vježbe, etide i poučavanje na osvijetljenim tipkama (25 minuta)
3. Proučavanje repertoara s video lekcijama i reprodukcijom na virtualnoj klavijaturi (30 minuta)
4. Čitanje s lista i improvizacija ili kreativni zadatci (15 minuta)
5. Povratne informacije i zadavanje domaćih zadaća unutar LMS-a (15 minuta)

Tijekom VR sesija aplikacija je u stvarnom vremenu bilježila MIDI i audiopodatke, analizirala visinu tona i ritmičku točnost, izračunavala preciznost takt po takt, otkrivala pogreške i generirala kratke preporuke. Sve su sesije automatski snimane (audio, MIDI i VR video iz prvog lica), a zapisi su se učitali na poslužitelj i prikazivali u nadzornoj ploči edukatora. Zabilježene mjere uključivale su vrijeme vježbanja, točnost izvedbe, statistiku pogrešaka i dodatne pokazatelje prikupljene iz VR aplikacije i LMS-a. Asinkrone videolekcije (svaka u trajanju od tri do osam minuta) bile su dostupne u VR-u i putem LMS-a. Kako bi se smanjila nelagoda, svakih 20 minuta bile su zakazane obvezne pauze od dvije minute, a sudionici su dobili detaljne sigurnosne upute.

Kontrolna je skupina slijedila isti kurikulum s obzirom na sadržaj i trajanje (dvije sesije od 90 minuta tjedno), ali u obliku tradicionalne nastave klavira uživo. Struktura sata bila je ista kao u eksperimentalnoj skupini:

1. Uvodno zagrijavanje (5 minuta)
2. Poučavanje tehnike pod vodstvom učitelja, uključujući demonstraciju i korekciju držanja i položaja ruku (25 minuta)
3. Učenje repertoara s analizom, zajedničkim izvođenjem i korektivnom povratnom informacijom (30 minuta)
4. Čitanje s lista i improvizacija (15 minuta)
5. Povratna informacija i zadavanje domaćih zadaća (15 minuta)

Kućna je praksa standardizirana u obje skupine. Svim je studentima preporučeno da vježbaju 30 minuta dnevno izvan zakazanih termina. Osim toga, eksperimentalna je

skupina poticana da tri puta tjedno obavi 20 – 30 minuta samostalne prakse temeljene na VR-u, s naglaskom na ponavljanje lekcija i tehničkih vježbi. Neravnomjernost u raspodjeli vremena dokumentirana je u odjeljku o ograničenjima: sudionici eksperimentalnoga poduzorka imali su dodatnih 60 – 90 minuta nastave temeljene na VR-u svaki tjedan. Prema trenutačnom dizajnu studije teško je razdvojiti doprinos povećanoga opsega vježbanja od specifičnoga pedagoškog učinka same VR tehnologije. VR platforma automatski je bilježila podatke o korištenju (vrijeme provedeno u aplikaciji, broj ponavljanja vježbi i pregleda videozapisa), dok je kontrolna skupina vodila elektroničke dnevnike vježbanja i učitala snimke na LMS. Vremena pristupa i korištenje materijala pratili su se automatski.

Postupci procjene obuhvaćali su provjeru na sredini semestra i završnu procjenu. Provjera na sredini semestra, provedena u šestome tjednu, uključivala je kratki zadatak tehničke izvedbe (jedan ulomak) i provjeru aktivnosti kućnoga vježbanja. Završno testiranje, provedeno u dvanaestome tjednu, repliciralo je dizajn preliminarnoga testiranja i uključivalo iste repertoarne ulomke, identične teorijske testove i dva nova ulomka za čitanje na prvi pogled.

Analiza podataka

Sve statističke analize provedene su pomoću verzije 26 SPSS programa. Za procjenu normalnosti raspodjele podataka primijenjen je Shapiro–Wilk test. Sukladno tome, Pearsonova analiza korelacije korištena je za normalno raspodijeljene parametre, dok je za podatke koji nisu zadovoljili pretpostavku normalnosti primijenjena Spearmanova neparametarska analiza korelacije. Usporedbe grupa provedene su Studentovim t-testom za normalno raspodijeljene podatke i Mann–Whitneyjevim U-testom za nenormalno raspodijeljene podatke. Analiza varijance (ANOVA) primijenjena je za istovremeno ispitivanje razlika između eksperimentalne i kontrolne skupine prema više parametara, kao i za procjenu utjecaja faktora „godina studija» i „grupa» na ishode učenja. Prije provođenja dvofaktorske ANOVA-e Leveneovim testom provjerena je pretpostavka o homogenosti varijanci između četiriju ćelija faktorskoga dizajna (eksperimentalna × 1. godina, eksperimentalna × 2. godina, kontrolna × 1. godina, kontrolna × 2. godina). Provedena je dvofaktorska analiza varijance (2 × 2) u kojoj su izračunate sume kvadrata tipa 3, pri čemu se svaki učinak procjenjuje nakon kontrole svih ostalih učinaka u modelu. Ovaj postupak osigurava ispravno tumačenje glavnih učinaka i interakcija u neuravnoteženim dizajnima jer se svaka procjena ocjenjuje uvjetno prema preostalim pojmovima modela (Maxwell i Delaney, 2004). Dodatno je korištena metoda za analizu vremenske točnosti izvođenja nota. Za kvalitativne podatke iz intervjuja korištena je analiza sadržaja.

Etički obziri

Istraživanje je provedeno uz poštivanje temeljnih etičkih načela, uključujući dobrovoljno sudjelovanje, informirani pristanak i povjerljivost podataka sudionika (Drolet i sur., 2023.). Svi studenti bili su unaprijed informirani o svrsi studije, metodama prikupljanja podataka i pravu na odustajanje u bilo kojem trenutku, bez negativnih posljedica.

Transkripti intervjuja i rezultati procjena korišteni su samo u objedinjenom obliku, bez otkrivanja osobnih podataka. U datotekama intervjuja svakom sudioniku je dodijeljen kod, a one su postavljene na sveučilišni poslužitelj i podijeljene sa stručnjacima za neovisnu evaluaciju bez uvida u pripadnost skupinama. Pisanu suglasnost za video snimanje i obradu podataka dobio je svaki sudionik u sklopu postupka davanja informiranoga pristanka.

Ograničenja

Ova studija ima nekoliko ograničenja. Uz uzorak od 150 studenata izabranih s dva konzervatorija, mogućnost generalizacije ostala je ograničena, pa su zaključci usko vezani uz specifičan kulturni i obrazovni kontekst. Dodatno je ograničenje činjenica da su obje institucije imale sličan pedagoški profil; visoka razina sličnosti njihovih kurikula dodatno je oslabila vanjsku valjanost.

Rezultati

U Tablici 2 predstavljena je komparativna dinamika četiriju ključnih indikatora (tehnika, muzikalnost, teorija i čitanje s lista) u eksperimentalnoj i kontrolnoj grupi prije i poslije nastave. Rezultati pokazuju znatno veća poboljšanja svih mjera u eksperimentalnoj skupini u usporedbi s kontrolnom skupinom. Prosječna ocjena iz klavirske tehnike porasla je s 11,24 na 17,86 (povećanje = 6,62, $t = 14,52$, $p < 0,001$, $d = 2,11$), dok se u kontrolnoj skupini povećala s 11,11 na 14,03 (povećanje = 2,92, $t = 8,03$, $p < 0,001$, $d = 1,17$).

Tablica 2

U poznavanju glazbene teorije rezultat eksperimentalne skupine poboljšalo se sa 7,82 na 12,93 (povećanje = 5,11, $U = 421,0$, $p < 0,001$, $r = 0,78$), dok se rezultat kontrolne skupine poboljšalo sa 7,76 na 10,32 (povećanje = 2,56, $U = 617,5$, $p < 0,001$, $r = 0,61$). Upotreba isticanja nota, sinkrone vizualizacije klavijature i notnoga zapisa, kontrole tempa i automatske identifikacije problematičnih dionica doprinijela je većem zabilježenom napretku.

U svim slučajevima razlike su bile statistički značajne na razini $p < 0,001$. Veličine učinka ($d = 1,88-2,11$; $r = 0,78-0,81$) ukazuju na snažnu praktičnu značajnost. Veća poboljšanja u eksperimentalnoj skupini mogu se objasniti kombinacijom čimbenika, uključujući multimodalnu povratnu informaciju, veću učestalost ciljanoga vježbanja, integraciju teorije i prakse te gamifikaciju procesa učenja.

Slika 2 prikazuje rezultate analize vremenske i ritmične točnosti odsviranih nota, odnosno relativni tempo svake note tijekom zadatka čitanja s lista jednoga studenta eksperimentalne skupine tijekom izvođenja fragmenta iz Schumannova *Albuma za mladež*. Izvor podataka u ovome grafikonu je profesorska nadzorna ploča, koja prikuplja podatke o studentima iz VR aplikacije i LMS-a. Slika uspoređuje izvedbu studenta s naznačenim tempom ($\text{♩} = 60$) prije (a) i nakon poučavanja (b).

Slika 2.

Slika „a” pokazuje da izvedba studenta (istočkana linija) značajno varira u odnosu na liniju idealnoga tempa ($y = 1,0$). Linija često odstupa prema gore i dolje, što pokazuje nestabilnost ritma i tempa. Ovaj rezultat pokazuje teškoće u tečnosti i točnosti pri reprodukciji glazbene kompozicije. Slika „b”, s druge strane, pokazuje značajno poboljšanje: linija izvedbe studenta mnogo je bliže idealnoj ($y = 1,0$), s rjeđim i manje naglim odstupanjima. Ovaj rezultat pokazuje da je student razvio veću kontrolu tempa i ritma, što se može izravno povezati s poučavanjem.

Kako bi ispitili učinke čimbenika „skupina” (eksperimentalna ili kontrolna) i „godina studija” (prva i druga godina) na ishode učenja, provedena je dvofaktorska analiza varijance (Tablica 3). Rezultati su pokazali da faktor „skupina” ima značajan učinak na klavirsku tehniku ($F = 124,52$, $p < 0,001$, η^2 _djelomično = 0,63) i muzikalnost ($F = 110,31$, $p < 0,001$, η^2 _djelomično = 0,60).

Tablica 3

Prema rezultatima ANOVA-e za klavirsku tehniku, faktor „grupa” objašnjava najveći udio varijance ($SS = 311,30$, η^2 _djelomično = 0,63); srednji kvadrat premašio je slučajnu pogrešku faktorom od 124,52. Faktor „godina studija” imao je skroman doprinos sumi kvadrata ($SS = 10,53$, η^2 _djelomično = 0,05) i dosegao statističku značajnost na razini od $p = 0,043$: studenti druge godine postigli su nešto više rezultate na posttestu jer im je veće iskustvo u glazbenom obrazovanju dalo neznatnu prednost u izvedbi.

U Tablici 4 prikazane su usporedbe po parovima procijenjenih marginalnih srednjih vrijednosti (EMM) s Bonaferronijevom korekcijom. Eksperimentalna skupina bila je značajno bolja od kontrolne u klavirskoj tehnici (srednja EMM razlika = 3,87, $SE = 0,26$, $p < 0,001$, 95 % CI [3,36; 4,38]) i muzikalnosti (srednja EMM razlika = 3,15, $SE = 0,27$, $p < 0,001$, 95 % CI [2,62; 3,68]). Razlike prema godinama studija značajne su u tehnici (srednja vrijednost EMM razlika = 0,65, $SE = 0,26$, $p = 0,043$, 95 % CI [0,14; 1,16]), dok učinak za muzikalnost nije pokazan (srednja EMM razlika = 0,49, $SE = 0,27$, $p = 0,053$, 95 % CI [-0,04; 1,02]).

Tablica 4

Usporedbe tijekom godine studija u tehničkom području dosegle su nominalnu značajnost ($p = 0,043$): studenti druge godine postigli su 0,65 bodova više od studenata prve godine; skromna razlika i mala vrijednost η^2 _djelomično (0,05) ukazuju na stvaran, premda mali, učinak akumuliranoga poučavanja. Što se tiče muzikalnosti, razlika od 0,49 bodova između godina nije zadovoljila kriterij $\alpha = 0,05$ ($p = 0,053$), što potvrđuje odlučujući čimbenik oblika nastave u poboljšanju izvedbe (Tablica 5).

Tablica 5

Slika 3 prikazuje vizualizaciju korelacijske analize četiriju glazbenih vještina: klavirske tehnike, muzikalnosti, čitanja s lista i teorije glazbe. Grafikon ilustrira međusobne odnose između vještina u obliku mreže, pri čemu je svaka vještina predstavljena čvorom, a

povezujuće linije označavaju jačinu korelacija. Debljina i boja linija označavaju stupanj povezanosti, dok su uz svaku liniju prikazani Pearsonovi koeficijenti korelacije kako bi se prikazala bliskost odnosa.

Slika 3.

Graf prikazuje snažne međusobne odnose između praktičnih izvedbenih vještina. Klavirska tehnika u snažnoj je korelaciji s muzikalnosti ($r = 0,81$) i čitanjem s lista ($r = 0,76$), što naglašava uzajamni utjecaj motoričke koordinacije, točnosti izvedbe i sposobnosti prenošenja umjetničke slike glazbenoga djela. Pokazalo se kako je muzikalnost također snažno povezana s čitanjem s lista ($r = 0,69$), što ukazuje na to da su te vještine uvelike međuovisne: što bolje izvođač čita glazbu, to se više može fokusirati na ekspresivnost, a bolja će biti i preciznost i tehnika. Korelacije s glazbenom teorijom bile su umjerene, ali statistički značajne, s utvrđenom povezanosti između teorije i tehnike ($r = 0,54$), čitanja s lista ($r = 0,57$) i muzikalnosti ($r = 0,49$).

Dobivene korelacije između tehničke izvrsnosti, muzikalnosti i sposobnosti čitanja s lista (r u rasponu od 0,69 do 0,81) ukazuju na prisutnost latentne varijable – faktor opće muzikalnosti bio je prisutan u svim mjerenim dimenzijama.

Analiza intervjua nadalje je otkrila da je većina sudionika pozitivno ocijenila upotrebu VR/internetskoga modela učenja (Slika 4). Najviše studenata, njih 86 %, svoju pozitivnu evaluaciju modela vezalo je za njegovu upotrebljivosti i vlastiti povećani angažman. Mnogi su izjavili da im je VR doživljaj pomogao da se usredotoče na materijal i smanje utjecaj ometajućih faktora.

Slika 4.

Diskusija

Rezultati ovoga istraživanja pokazuju da upotreba VR/internetskoga modela u nastavi glazbe značajno poboljšava stjecanje temeljnih vještina u usporedbi s tradicionalnim metodama. Eksperimentalna skupina pokazala je značajna poboljšanja u svim pokazateljima: klavirska tehnika povećala se za 6,62 boda, muzikalnost za 6,15 bodova, znanje glazbene teorije za 5,11 bodova, a čitanje s lista za 7,09 bodova. Iako je kontrolna skupina također pokazala napredak, postignuća su bila manja: tehnika (+2,92), muzikalnost (+3,18), teorija (+2,56) i čitanje s lista (+4,10). Značajno poboljšanje muzikalnosti u eksperimentalnoj skupini može se pripisati jedinstvenim značajkama nastave temeljene na VR-u: integriranim videodemonstracijama instruktora, ponovnom pregledavanju fraza, sinkronim vizualnim signalima za dinamiku i fraziranje te u sigurnom virtualnom okruženju koje je smanjilo tremu od nastupa i potaknulo svjesniji rad na ekspresivnosti. Ovaj učinak podupire teoriju prisutnosti, koja objašnjava kako uranjanje u VR okruženja povećava angažman i poboljšava ishode učenja (Triberti i sur., 2025). Slični su rezultati izviješteni u studijama Han i sur. (2025) i Li i sur. (2025), u kojima je integracija VR-a i internetskih platformi poboljšala akademski uspjeh studenata i vještine sviranja klavira. Uočene su veličine učinka u rasponu od $d = 1,88$ do 2,11.

Prema klasifikaciji koju je predložio Hattie (2008), vrijednosti koje premašuju $d = 1,0$ smatraju se „vrlo velikim» učinkom. Dvostruko premašivanje toga praga potaknulo je pažljivo ispitivanje mogućih metodoloških čimbenika. Pet konvergentnih čimbenika moglo je pridonijeti uvećanju veličine učinka. Prvo, sudionici u eksperimentalnoj skupini dobili su dodatno vrijeme za vježbu, dok je tehnološka novost VR-a mogla privremeno povećati angažman, čime je stvoren prvi par utjecaja. Drugo, Hawthorneov efekt – poboljšanje učinka koje proizlazi iz spoznaje sudionika da su promatrani – zajedno s općenito visokom intrinzičnom motivacijom karakterističnom za studente konzervatorija, dodao je još dvije komponente. Konačno, nedostatak postupaka evaluacije bez poznavanja pripadnosti skupinama stvorio je uvjete pod kojima su stručne ocjene mogle biti nenamjerno precijenjene. Stoga će budući eksperimenti zahtijevati primjenu aktivnih kontrolnih uvjeta i protokola dvostruke evaluacije bez poznavanja pripadnosti skupinama. Važno je napomenuti da ovaj rad nudi pregled istraživanja o glazbenome obrazovanju temeljenom na VR-u koja nisu koristila usporedive metodološke dizajne.

Zaključak

Rezultati studije pokazali su da je primjena VR/internetskoga modela za poučavanje klavira dovela do značajnih poboljšanja u svim mjerenim pokazateljima u usporedbi s tradicionalnim pristupom. U eksperimentalnoj skupini zabilježen je vrlo visoki učinak na klavirsku tehniku ($d = 2,11$), što naglašava praktičnu važnost korištene metode. Smanjenje standardne devijacije nakon poduke (s 2,15 na 1,42) ukazalo je na izjednačavanje učinka sudionika, što sugerira da je platforma omogućila manje iskusnim studentima da se približe naprednijim kolegama. Najveća poboljšanja zabilježena su u vještini čitanja s lista ($r = 0,81$) i klavirske tehnike, što naglašava znatan utjecaj VR/internetskoga modela na razvoj praktičnih izvedbenih sposobnosti. Faktor „grupa” bio je značajan za sve pokazatelje, dok je faktor „godina studija» bio značajan samo za tehniku, s malim učinkom ($\eta^2 = 0,05$), nisu utvrđeni interakcijski učinci. Korelacijske analize otkrile su jaku povezanost između tehnike, muzikalnosti i čitanja s lista, pri čemu je glazbena teorija imala usporedno slabiji utjecaj. Podatci iz kvalitativnih intervjuva dodatno su ukazali na to da je VR/internetski model ne samo poboljšao stjecanje vještina, već i povećao motivaciju i zadovoljstvo učenjem.