Bridging Cello Learning with Technological Innovations: An Exploration of Interaction Design Opportunities

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Abstract. Incorporating emotional design, user-centered design, music education insights, and cognitive load management, this study investigates the integration of AI into cello learning. Through competitive analysis and qualitative user research, including detailed observations and interviews, we introduce interaction design solutions of "Goal-Oriented Three Practice Modes", "Interactive Learning", and "Personalized Practice Plans". This research aims to make classical music education more efficient, accessible and personalized, addressing economic and geographical limitations. By integrating technological innovations, we seek to enrich the classical music tradition, enhance the cello learning experience, and expand the community for cello learners and enthusiasts.

Keywords: User Experience · Qualitative User Research · Artificial Intelligence · Cello · Music Education · Interaction Design Solutions

1 Introduction

The cello, a cornerstone of classical music with centuries of history, commands a unique and revered place in the orchestral and solo performance realms. Renowned for its deep, resonant tones that closely mimic the range and timbre of the human voice, the cello offers a profound emotional depth and versatility unmatched by other string instruments. Its rich, sonorous sound, capable of conveying a wide spectrum of emotions, from melancholic whispers to exuberant jubilations, has cemented its role as a pivotal element of symphonic compositions and solo repertoire alike. This instrument's breadth in lower sound ranges allows it to serve as the backbone of the string section in orchestras, providing a critical counterpoint to the brighter violins and violas, and harmonizing with the double basses to create a full, cohesive sound.

However, cultivating cellists presents significant challenges due to high entry barriers. Firstly, mastering the cello demands precise technique and posture, challenging for beginners and potentially risky for professionals due to the long practice sessions required [1]. Secondly, a career in cello performance necessitates lifelong practice to learn new pieces and maintain skills, which are crucial for performances [2]. Moreover, the cello's size contributes to higher learning costs and transportation difficulties, compounding the challenge of finding and affording quality instruction, especially in less

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developed regions [3]. These barriers restrict access for those with limited resources, narrowing learning and career opportunities. Consequently, this impedes the popularization of the cello, reducing the number of learners and professionals, and potentially affecting the spread and development of classical music in the digital age.

The advent of Artificial Intelligence (AI) has ushered in a new era of interdisciplinary integration, challenging and expanding the boundaries of traditional domains, including the arts. Innovations such as MidJourney [4] and DALL-E 3 [5] have not only demonstrated AI's capability to collaborate within creative fields but have also ignited a conversation about the role of AI in understanding, creating, and even critiquing art. This dialogue encompasses AI's potential to grasp the nuances of artistic expression, make aesthetic judgments, and perhaps most provocatively, the extent to which it could complement or even substitute human artists. The rapid evolution of AI technologies hints at an expansive future for their application in the arts, promising unprecedented tools for creative expression and interpretation.

In light of these advancements, our exploration delves into how AI technology can be specifically leveraged to revolutionize cello education and daily training. By identifying and harnessing opportunities in interaction design, we propose the development of a user-centered, technologically advanced cello practice platform. This initiative is grounded in the application of music education principles and cognitive load theories, supplemented by an analysis of existing market solutions and insights from qualitative user research. Our aim is to dismantle economic and geographical barriers that hinder access to cello learning, thereby enhancing the learning experience for cellists.

2 Literature Review

This research delves into the learning motivation, practice processes, and experiences of cello players to uncover opportunities for applying AI technology in enhancing cello practice. To attain a comprehensive understanding of the experiences and needs of our target users, the theoretical framework of this study synthesizes insights from several interconnected domains. Specifically, we review literature on emotional design, music education, and working memory from cognitive studies. This multidisciplinary approach enables us to explore how emotional engagement influences learning, the pedagogical strategies that most effectively support music education, and the role of working memory in mastering complex skills.

Firstly, Donald Norman's theory of emotional design [6] underscores the importance of addressing users' emotional needs to enhance the appeal and usability of products. In the context of designing an application to boost learning motivation and practice efficiency for cello players, Norman's insights are invaluable. Our approach integrates user-centered design principles [7], which place the needs, preferences, and behaviors of users at the core of the development process.

In the realm of music education, the Dalcroze Eurhythmics method emerges as a pivotal approach, underscoring the essence of sensing, feeling, and listening as fundamental attributes of a musician [8]. This perspective is further enriched by Rosalind Ridout [9], a renowned flute performer, who articulates the multifaceted challenge of mastering a classical music piece. According to Ridout, achieving excellence in performance demands not only advanced instrumental technical skills and flexibility but also cognitive prowess for interpreting notation and rhythm. Furthermore, it requires a creative interpretation of techniques and musical colors, alongside a profound musical understanding to captivate and engage audiences. Adding to this discourse, Schiavio et al. [10] spotlight the ensemble as a crucial learning environment that fosters the ability to listen and respond to others, emphasizing the significance of time management, self-comparison within a group context, and the cultivation of responsible learning methodologies. Collectively, these perspectives illuminate the critical role of sensory engagement and listening in the process of music education. They delineate the array of skills and competencies essential for delivering a compelling performance, laying a solid theoretical foundation for the design and functional emphases of our music learning application.

Our design approach is deeply influenced by the working memory model proposed by Baddeley and Hitch [11], which serves as a pivotal framework for managing cognitive load in the development of applications for instrument learning. This model underscores the importance of preventing information overload to avoid overwhelming users. Further expanding on this foundation, the enhancements brought forth by Cowan's Embedded Process model [12] highlight the dynamic nature of working memory and its capacity limits, offering nuanced insights into how information is temporarily stored and manipulated. Additionally, the concept of cognitive load theory by Sweller [13] provides essential guidelines for instructional design, emphasizing the need to minimize extraneous load while optimizing intrinsic and germane loads for better learning outcomes.

The synthesis of literature not only presents the critical roles of emotional connection, pedagogical efficacy, and cognitive capacity in music education but also sets a theoretical backdrop for integrating AI in cello practice. As we pivot from theoretical insights to practical applications, we next explore existing projects in AI-assisted music education.

3 Related Work

3.1 Advancements in AI for Music Performance and Analysis

The intersection of artificial intelligence with music performance and analysis has seen remarkable advancements. Weinberg et al. [14] have harnessed computer vision to dissect drummers' movements, providing insights into the nuanced interplay between human performers and their instruments. In a comprehensive exploration, Miranda's book [15] compiles studies on various dimensions of AI in music, including the intricate dynamics of human-machine interactions. Similarly, Duke et al. [16] leverage computer vision technology to translate visual cues into musical notes, opening new avenues for interpreting performances. Blanco et al. [17] delve into analyzing the movements and sound quality of violinists, employing AI to discern the sound characteristics of a violin, categorizing them into descriptors such as "Gentle," "Excited," "Warm," and "Tight" [18].

Furthermore, Dalmazzo and Ramirez [19] have developed a model capable of classifying the bowing techniques of violinists, showcasing the potential of AI to understand and replicate complex musical gestures.

Recent developments in AI have ventured beyond analysis to the replication of human vocal nuances, creating content that increasingly blurs the boundaries between authentic and synthetic sounds. YouTube's introduction of the AI-powered Dream Track [20] enables users to emulate the voices of renowned singers, allowing the creation of short musical pieces tailored with specific lyrics and emotional tones. Additionally, the proliferation of AI voice cloning tools [21] empowers users to produce songs and speeches in any language, utilizing samples of existing voices. These technological leaps forward herald a future where AI could not only analyze and recognize individual performance styles for personalized enhancement but also generate new performances that faithfully mirror a particular artist's unique style.

3.2 Existing Music Learning Products Review

The market is currently filled with a variety of products designed for music learning, available on platforms including smartphones, tablets, and VR headsets. In pursuit of an innovative design, we have carefully selected and analyzed five applications focused on musical instrument practice (see Table 1). Our selection criteria were based on product popularity, integration of AI technology, and the specific relevance to cello instruction. The evaluation of the advantages and disadvantages of each application was informed by real user reviews gathered from the applications' official websites, as well as feedback from the App Store, Google Play Store, and Meta Quest App Store [22–26].

Beyond the applications listed in the table, we observed that tools specifically designed for cello learners are scarce and often limited in functionality. This gap presents a significant opportunity for leveraging AI technology in cello education, aiming to provide advanced cello players with a more efficient, comprehensive, and intelligent learning experience. Moreover, despite numerous demonstrations of technology's benefits, many musicians remain wary of incorporating such tools into their practice. Our preliminary survey revealed that only one out of 57 musicians regularly uses AI in their work, specifically the MyPianist app. This reluctance may be attributed to the deep-rooted traditions in music or apprehensions about AI, including fears of job displacement. However, an overwhelming 91% of respondents indicated a willingness to explore the potential of technology. Through this review, our goal is to develop digital solutions tailored to the unique challenges faced by cello players, with a focus on user-friendly interfaces that facilitate meaningful and transformative practice experiences.

Table 1. Existing music learning products review

Product Name	MyPianist	PianoVision	Yousician
Type	Mobile app	MR glasses app	Mobile app
Target Music Instrument	Any instrument	Piano	Guitar, Singing and Bass
Main User	All skill levels instrumentalists	All skill levels Piano player	Beginners and intermediate learners
Main Feature	Provides adaptive piano accompaniment based on live classical music playing	Turns surfaces into virtual keyboards with Meta Quest for 3D music interaction	· Instant performance feedback · Structured learning paths · Gamified learning experience
Technology	· AI · Real-time Audio Signal Processing	· Mixed Reality · Computer Vision	Real-time Audio Signal Processing
Pros	· Responsive accompaniment improves playing · Automatic tempo adjustment simplifies practice · Simulated ensemble enriches string practice	· Enhances practice immersion and enjoyment · Increases accessibility for beginners and amateurs with intuitive design	· Professional structured learning · Engaging interaction to keep learners motivated
Cons	Recognition accuracy is unstable when instrument sound blending it with piano accompaniment	· Prevent practicing sight-reading · Functions more as a musical game than a learning tool	· Unable to assess beginners' formation of correct playing habits · Lacks advanced content for experienced players

Product Name	Violy	Cello Coach
Type	Mobile app	Mobile app
Target Music Instrument	Mainly Violin and Piano	Cello
Main User	Music educators and learners	Intermediate or above cellists with a grasp of basic techniques
Main Feature	· Score-synced demonstration videos · Adjustable practice accompaniment. · Intonation and rhythm correction	· Real-time feedback on intonation and scale practice · Adjustable tuning · Progress tracking
Technology	· AI scoring · Real-time Audio Signal Processing	· Audio Signal Processing · Tailored Feedback Algorithms
Pros	· Comprehensive functions	· Professional content Targets cello

(*continued*)

Table 1. (*continued*)

	· Hands-free music initiation through unique interaction · Instructional videos for effective learning · Detailed practice reports aid in error correction	practice · Effective for tuning and refining intonation and note accuracy
Cons	· Low scores discourage young learners · Correction and repetitive practice is not motivating · No customization when version is different between app and textbook	· Limited basic functions · Insufficient guidance for beginners · Practice is repetitive and lack motivation

4 Methodology of the User Research

4.1 Design of the Research

This article adopts qualitative research methodologies to conduct user experience studies, focusing on observations of one-on-one cello lessons and interviews with cello players. By observing and engaging with users about their motivations for learning the cello, along with their experiences and emotions during the learning and practice processes, this study aims to uncover both the technical and emotional needs of cello practitioners. Additionally, by analyzing firsthand learning and practice experiences, we explore opportunities for translating these insights into interaction design and for the potential integration of AI technology to support cello practice. The research is guided by the following questions:

1. When do musicians typically encounter challenges during practice?
2. What type of guidance do they seek to enhance their performance skills?
3. How do musicians perceive the role of AI assistance within the context of music practice?

4.2 Recruitment of Participants

This research received approval from the Institutional Review Board (IRB) at Purdue University with approval study number IRB-2023-551. Participants were recruited through a variety of channels, including postings on social media platforms and through personal networks, to ensure a diverse and representative group of participants.

To maintain the validity of the research, all participants underwent a review process before inclusion in the study. Each participant was required to have at least one year of experience learning the cello and to have been regularly practicing the cello in the past year. This criterion was set to ensure that participants could provide insightful feedback on the learning process. Prior to participation, all participants were informed about the study purpose, which is to design digital assistance for enhancing the cello learning and practice experience and efficiency. Interviews were recorded with the consent of the interviewees, and participants were assured that these recordings would be used exclusively for research documentation and not for any other purposes. Furthermore, participants were informed that they might be invited to partake in usability testing and evaluation of the designed digital assistance in the future, with their consent obtained at each stage to ensure their comfort and agreement.

The study involved a total of 7 participants, comprising 5 females. Their experiences with the cello varied and included: one cello musician and university professor, one master's student specializing in cello, two undergraduate students specializing in cello, one cello enthusiast also specializing in piano, one amateur cello player who participates in orchestra performances, and one beginner cello player (see Table 2).

Table 2. Data of participants

No	Gender	Occupation	Cello Experience Level
1	Female	Cello musician/ Educator	Professional
2	Male	Cello major graduate student	Professional
3	Female	Cello major undergraduate student	Advanced
4	Male	Cello major undergraduate student	Advanced
5	Female	Piano major undergraduate student	Intermediate
6	Female	Software engineer	Intermediate
7	Female	Data Analyst	Beginner

4.3 Method of Observation

We conducted observations of one-on-one, in-person cello studio classes, each lasting 30 min, completing two sessions in total. The participants in these sessions were numbered 4 and 5, respectively. Our observations focused on various aspects of cello practice, including the procedural steps under the guidance of a professional teacher, methods employed in learning new pieces, challenges encountered by the learners, and the instructional support provided by the teacher. Throughout these observations, researchers meticulously documented the interactions between the participants and the teacher, as well as between the participants and both the cello and their surrounding environment, using detailed field notes.

4.4 Format of the Interview

This study utilized semi-structured interviews, conducting six one-on-one sessions with participants numbered 1, 2, 3, 5, 6, and 7. Each session varied in length from 30 min to an hour. The interviews were conducted using video conferencing software (e.g., Zoom) and were audio-recorded with the participants' prior consent. Researchers captured data through notes taken during the interviews in addition to the audio recordings. The primary aim of the interviews was to gather participants' feedback on their learning experiences, instructional preferences, and views on traditional versus modern learning methods, with a particular focus on digital support. With the consent of the participants, the sessions were audio-recorded to enhance the thoroughness of data collection and analysis.

4.5 Grounded Theory in Data Analysis

Drawing on Khan's insights into qualitative research [27], our study adopts a grounded theory approach for the analysis of data garnered from interviews and observations. This method, characterized by its bottom-up analytical strategy, embraces the inherently unstructured nature of the collected data to unearth patterns and themes organically. By eschewing biases inherent in the functionalities of existing applications, this approach ensures that our analysis remains unencumbered by preconceived notions about the challenges and types of assistance required during cello practice. This not only guarantees that our findings are rooted in fresh insights gleaned from the collected data but also facilitates a thorough examination of the nuanced interactive experiences of cello practice. Consequently, this method paves the way for the formulation of a user experience model that unveils innovative design opportunities, firmly anchored in empirical evidence.

5 Data Analysis

5.1 Data Preparation

Data from the two observations were meticulously recorded in detailed field notes, which included mappings of the scene, observations of participant behavior, language used, interactions observed, and comments from the observer. Additionally, six semi-structured interviews were audio-recorded and subsequently transcribed to facilitate analysis.

For data processing and analysis, thematic analysis [28] was employed. The process began with the identification of noteworthy and relevant quotes from the field notes and interview transcripts. Following this, coding was conducted manually using these quotes to create an affinity diagram, which helped in identifying emerging themes. This led to the construction of a network of interconnected themes. The analysis ultimately highlighted several dominant themes, each substantiated by direct quotes from the participants.

5.2 Thematic Analysis of the Challenges in Cello Practice

Observation. During our in-person observations of one-on-one cello classes, we concentrated on the interactions between learners and teachers, as well as the interactions between learners, their instruments, and the surrounding environment. The objective was to grasp the learning and practice processes of the cello, identify the challenges faced by participants, and understand the support and guidance provided by teachers. These observations helped us pinpoint design opportunities for transferring offline cello learning experiences into an online setting.

Throughout the observation of cello classes, significant quotes were noted on sticky notes from the field notes (see Fig. 1), and an affinity diagram was employed to code and categorize similar quotes pertaining to various aspects of cello practice (see Fig. 2). This approach resulted in the identification of five key themes:

1. Posture Challenges: The importance of correct posture in cello learning was evident, with teachers frequently making real-time corrections.
2. Practice Process: Classes typically begin with the basics, such as playing scales and confirming intonation by singing, progressing to reading scores and playing sections together before moving on to solo practice. This sequence reflects the comprehensive steps and methods involved in learning new pieces.
3. Timely Feedback: Teachers provide crucial, timely feedback during practice, offering both encouragement and constructive critique.
4. Guidance from the Teacher: One-on-one instruction facilitates invaluable guidance, blending professional expertise with personalized analysis for a thorough evaluation and strategic planning.
5. Physical and Cognitive Load: Participants encounter both physical and cognitive challenges, including maintaining posture, managing muscle soreness, juggling score pages and notes while holding the bow, and concentrating on multiple elements simultaneously, such as score reading, sound quality, posture, finger and bow positions, and dynamics. For instance, a participant was observed repeating a section inadvertently due to attention overload.

Our analysis of these themes revealed several insights into the nuanced challenges of cello practice, highlighting areas for potential intervention and support through digital solutions.

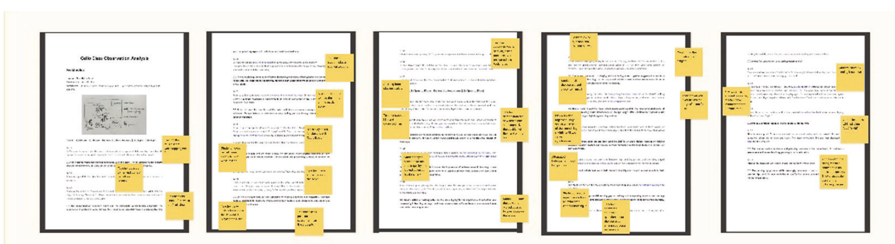

Fig. 1. The process of quoting from observation field notes.

Interview. During the semi-structured interviews, we focused on the participants' cello learning experience and motivation, challenges they face, the guidance they seek, and their opinions on AI technologies.

After the interviews, quotes were noted on sticky notes from the transcripts (see Fig. 3).

The analysis process employed a two-stage thematic analysis. Initially, the quotes were coded to identify primary themes. Subsequently, a more granular coding was conducted within these broad themes to define secondary themes, allowing for a nuanced

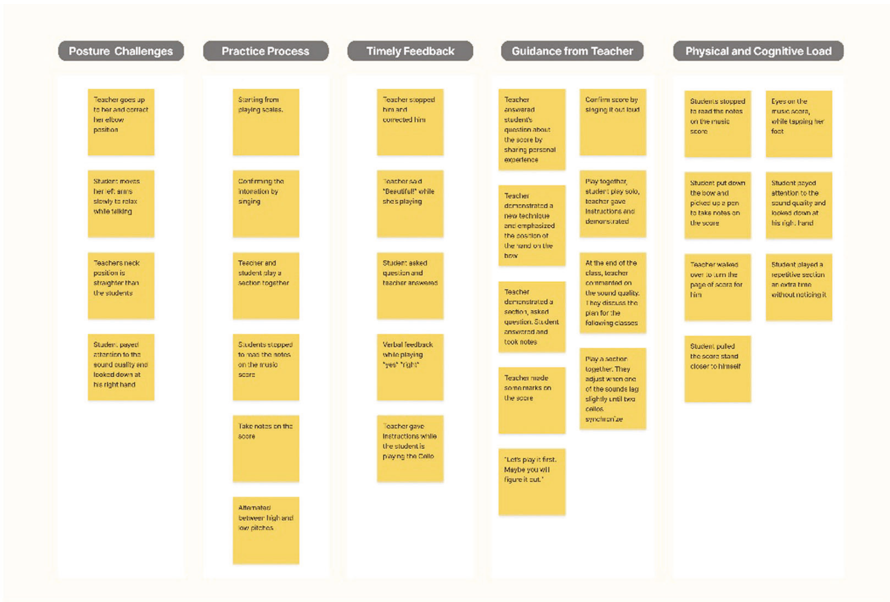

Fig. 2. Affinity diagram of cello practice themes from observational quotes.

Fig. 3. Quotes from the six interview transcripts.

understanding of the interview data. The results of the two-level themes are presented in the affinity diagram (see Fig. 4). This approach resulted in the identification of seven primary themes and the secondary themes of each primary theme:

1. Motivation: Participants are driven to practice the cello due to their "love for music", desire for "interaction with people" through ensembles, and aims for "academic and career development". Many have dedicated significant time and effort towards specific

objectives like auditions, exams, competitions, and performances, either solo or with an orchestra.

2. Challenges: Common obstacles include the mental and physical exhaustion from "long and repetitive practice sessions", the struggle with "limited attention and self-awareness" in solitary practice without a teacher, and difficulties in mastering cello techniques such as "maintaining proper posture, fingering, and bowing", achieving "correct intonation", and realizing the desired "music interpretation".
3. Guidance/Method: To overcome these challenges, participants adopt strategies like creating a "practice plan" and focusing on individual techniques. They value expert advice, seeking "personal tips shared by professionals" and emulating performances from master videos. Tools like tuners and metronomes are utilized, alongside finding "accompaniment practice with timely feedback" crucial.
4. Practice Process: Practices commence with a review of "basic skills" across all skill levels, progressing methodically when "learning a new piece" until mastery is achieved.
5. Emotional Needs: The importance of "encouragement and support from friends and teachers" is emphasized for a more enjoyable practice experience, with one participant noting a profound "connection with the cello".
6. Criteria for Solo and Orchestra: While personal interpretation is acknowledged, there is consensus on evaluating orchestras based on technique and interpretation uniformity, and solos primarily on musicality.
7. Thoughts on AI: There is optimism that AI can offer "humanized interaction" and "personalized plans" through machine learning. "Timely and responsive feedback" from AI is seen as beneficial for efficiency, with its "accuracy and rigor" being particularly useful for orchestral practice. Concerns are raised about AI's capability in "music interpretation" for solo performances, given its subjective nature.

Following the identification of primary and secondary themes, we arranged these themes into a thematic network (see Fig. 5), focusing on their logical connections and relevance. This organization led to the following key observations:

1. Participants' motivation for practicing the cello is pivotal in setting their goals and refining their approach to practice, necessitating targeted methods for diverse evaluation criteria in auditions and competitions.
2. Our analysis of practice challenges, alongside participants' emotional needs and AI capabilities, has informed the conceptualization of our application's guidance features.
3. The perception of AI's credibility across musical aspects has been instrumental in tailoring our application's functions to meet user expectations.
4. AI's unique features address varied needs, with "personalized plans" enhancing practice sessions and "accuracy and rigor" in evaluations aiding in meeting orchestra performance criteria.

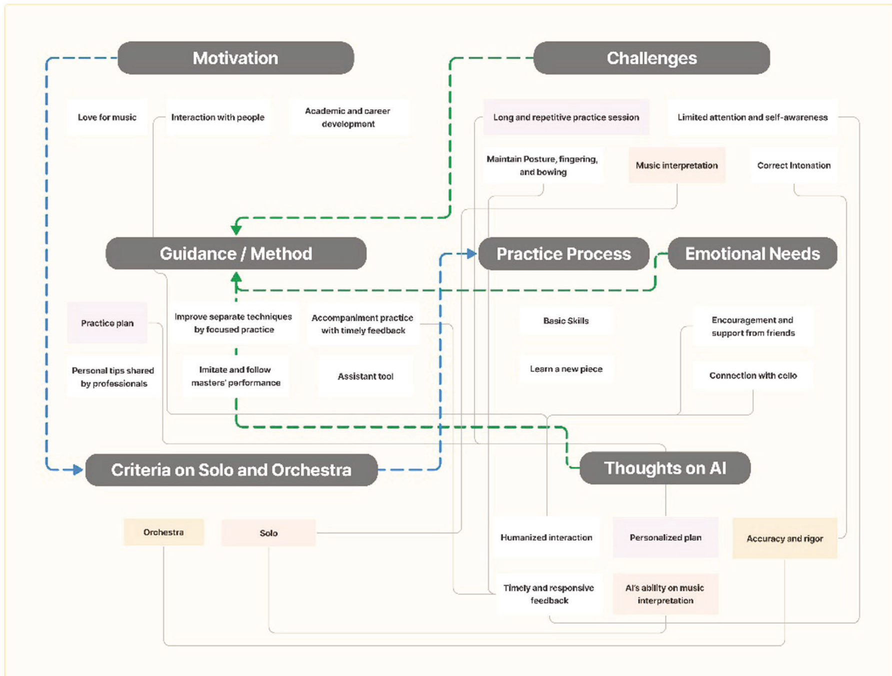

Fig. 4. The network of themes.

6 Design Directions

6.1 Synthesis of Design Principles

Our design direction is underpinned by a theoretical framework that integrates emotional design, user-centered design, the principles of sensing and listening from music education, and cognitive load management. These guiding theories emphasize the creation of interfaces that resonate emotionally, enhance usability, foster musical skill development through sensory engagement, and ensure cognitive loads are manageable. Our objective is to refine the learning experience, making practice more efficient and enjoyable for cello players.

A critical analysis of existing music education applications highlighted the necessity to amalgamate the best features while eliminating the least effective ones. Initially, identifying the target user group and categorizing users based on their objectives is crucial. This allows for the design of varied modes that cater to the specific needs of different user groups, striking a balance between professionalism and entertainment. Furthermore, our design seeks to integrate multiple functionalities to obviate the need for multiple devices during practice, thereby addressing the gap in comprehensive cello education software. Lastly, it is essential to explore new interaction modes that are conducive to cello practice scenarios.

6.2 Design Solutions

To address the identified needs and enhance the learning experience for cello players, we propose three major design solutions: Goal-Oriented Three Practice Modes, Interactive Learning, and Personalized Practice Plan.

Goal-Oriented Three Practice Modes. Insights from user interviews revealed the importance of aligning practice modes with user goals. Consequently, we introduced three distinct practice modes: Piece Learning, Orchestra Prep, and Soloist. The Piece Learning mode concentrates on score analysis, familiarizing users with musical scores, and understanding musical emotions. Orchestra Prep mode is designed for rigorous pitch and rhythm training, including accompaniment practices to refine performance precision. The Soloist mode offers flexibility, allowing users to explore pitch and rhythm, and analyze styles of cello masters for personalized musical interpretation.

Interactive Learning. This feature is refined to offer real-time, AI-driven feedback on posture through computer vision and intonation accuracy via sound recognition. Instructions and encouragement tailored to real-time progress during practice sessions will keep high engagement. During practice, the music score will automatically scroll to align with the progress, and highlight the section being played, minimizing the need to manually turn pages, which ensures a smoother practice session and aids in maintaining concentration. Voice and instrumental interaction for annotating scores directly and AI-driven highlights for areas needing improvement streamline the learning process by allowing continuous play without the interruption of traditional note-taking methods.

Personalized Practice Plan. The system crafts a personalized practice plan aligned with the user's long-term goals, breaking them down into daily, detailed schedules tailored to the user's skill level and specific objectives. Leveraging AI technology, the plan adjusts dynamically based on practice evaluations and interruptions, supporting continuous progress. AI also customizes practice duration based on the learner's physical and mental state, suggesting rest periods to prevent fatigue. Post-session, an analytical review identifies errors, summarizes challenges, and offers targeted recommendations, thus fostering sustained motivation and improving practice efficiency.

7 Credibility and Dependability

This study's participants spanned from beginners to professionals, ensuring a broad perspective on cello learning and practice experiences. Interviews delved into relevant topics like practice challenges and learning experiences, while observations highlighted effective learning strategies and interactions. These insights directly address the research goals, confirming the study's validity. The credibility of our findings is further supported by contributions from university professors specialized in cello performance among the research team and participants. Their expertise, combined with the consistency of themes across diverse interviews, such as practice routines and performance standards, enhances the study's reliability.

8 Future Plan and Limitations

The rapid advancements in AI within music education present a duality of excitement and concern among cellists. Enthusiasm exists for AI's potential to improve practice efficiency and concentration; however, doubts persist regarding its capacity to assess human musicality and the fear of it supplanting certain teaching roles. This ambivalence mirrors historical reactions to the industrial era's shift towards mechanization, which made goods more accessible and lessened wealth disparities but at the expense of the handmade items' distinctiveness. In a similar vein, AI's evolution in music education could democratize access to classical instrument learning, like the cello, by boosting practice efficiency and tailoring the educational experience. AI aims to augment rather than replace human musicians or educators, thereby freeing up more time for creative expression. Additionally, generative AI applications could offer a deeper emotional connection to music than traditional educational software has achieved.

This study recognizes the challenge for interaction designers without a cello background in creating a comprehensive cello learning tool. Nevertheless, through empathetic user engagement and a robust understanding of user needs derived from observations and interviews, we have identified significant opportunities for innovative interaction designs. Future research will explore these avenues further, with plans for collaboration with professional musicians and comprehensive usability testing to refine and validate our design solutions.

9 Conclusion

This research aimed to uncover interaction design opportunities by applying AI technology to the specific challenges of cello learning. We developed solutions like Goal-Oriented Three Practice Modes, Interactive Learning, and Personalized Practice Plans, grounded in user-centered design, music education insights, cognitive load management, competitive analysis, and qualitative user research.

Our integration of AI into cello practice seeks to make classical music education more accessible, engaging, and personalized, addressing economic and geographical limitations. This initiative strives to improve the cello learning experience, widen access to classical music education, and democratize the learning process. By leveraging AI innovations, we aim to enhance the classical music tradition with new learning opportunities and creative possibilities, making cello practice more appealing and fostering a broader community of learners and enthusiasts.

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References

1. Rietveld, A.B.M.: Dancers' and musicians' injuries. Clin. Rheumatol. **32**, 425–434 (2013)

2. National Endowment for the Arts.: Artists and other cultural workers: A statistical portrait. NEA, Washington, District of Columbia (2019)
3. Beveridge, T.: Does music education have a poverty problem? Update: Appl. Res. Music Educ. **40**(2), 10–18 (2022)
4. MidJourney Homepage. https://www.midjourney.com/home. Accessed 14 Feb 2024
5. DALL·E 3 Homepage. https://openai.com/dall-e-3. Accessed 14 Feb 2024
6. Norman, D.A.: The Design of Everyday Things: Revised and Expanded Edition. Basic Books (2013)
7. Garrett, J.J.: The Elements of User Experience: User-Centered Design for the Web and Beyond (2nd Edition). New Riders (2011)
8. Jaques-Dalcroze, E.: Rhythm, Music and Education, Trans. H. F. Rubenstein. The Dalcroze Society, London (1967)
9. Ridout, R., Habron, J.: Three flute players' lived experiences of Dalcroze eurhythmics in preparing contemporary music for performance. Front. Educ. **5**, 18 (2020)
10. Schiavio, A., Küssner, M.B., Williamon, A.: Music teachers' perspectives and experiences of ensemble and learning skills. Front. Psychol. **11**, 291 (2020)
11. Baddeley, A., Hitch, G.: Working Memory. Psychol. Learn. Motiv. Adv. Res. Theor. **8**, 47–89 (1974)
12. Cowan, N.: An embedded-processes model of working memory. Models Working Mem. Mech. Act. Maintenance Executive Control **20**(506), 1013–1019 (1999)
13. Sweller, J.: Visualization and instructional design. In: Proceedings of the International Workshop on Dynamic Visualizations and Learning, vol. 18, pp. 1501–1510 (2002)
14. Weinberg, G., et al.: "Watch and Lear"—Computer Vision for Musical Gesture Analysis. In: Robotic Musicianship: Embodied Artificial Creativity and Mechatronic Musical Expression, pp. 189–212 (2020)
15. Miranda, E.R.: Handbook of Artificial Intelligence for Music: Foundations, Advanced Approaches, and Developments for Creativity. 2nd edn. Springer International Publishing AG (2021)
16. Duke, B., Salgian, A.: Guitar Tablature Generation Using Computer Vision. In: Bebis, G., et al. (eds.) ISVC 2019. LNCS, vol. 11845, pp. 247–257. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-33723-0_20
17. Blanco, A.D., Tassani, S., Ramirez, R.: Real-time sound and motion feedback for violin bow technique learning: a controlled. Randomized Trial. Front. Psychol. **12**, 648479 (2021)
18. Musical performance & education with AI. https://www.artificia.pro/musical-performance-education-with-ai/. Accessed 15 Feb 2024
19. Dalmazzo, D., Ramírez, R.: Bowing gestures classification in violin performance: a machine learning approach. Front. Psychol. **10**, 344 (2019)
20. An early look at the possibilities as we experiment with AI and Music, https://blog.youtube/inside-youtube/ai-and-music-experiment/. Accessed 14 Feb 2024
21. Retrieval-Based-Voice-Conversion-WebUI. https://github.com/RVC-Project/Retrieval-based-Voice-Conversion-WebUI. Accessed 14 Feb 2024
22. MyPianist: A.I. accompanist. https://apps.apple.com/us/app/mypianist-a-i-accompanist/id1460393665. Accessed 14 Feb 2024
23. PianoVision. https://www.meta.com/experiences/5271074762922599/. Accessed 14 Feb 2024
24. Violy SyncedDemo & MusicSheet. https://apps.apple.com/us/app/violy-synceddemo-musicsheet/id1357516375. Accessed 14 Feb 2024
25. Yousician: Learn & Play Music. https://apps.apple.com/us/app/yousician-learn-play-music/id959883039. Accessed 14 Feb 2024
26. Cello Coach. https://play.google.com/store/apps/details?id=net.precise_team.cellocoach&hl=en_US&gl=US. Accessed 14 Feb 2024

27. Khan, S.N.: Qualitative Research Method: Grounded Theory. (n.d.). International Journal of Business and Management (2014)
28. Braun, V., Clarke, V.: Thematic analysis. In: Cooper, H., Camic, P. M., Long, D.L., Panter, A.T., Rindskopf, D., Sher, K. J. (eds.) APA Handbook of Research Methods in Psychology, Vol. 2, pp. 57–71. American Psychological Association (2012)