eScore: An MVP for Solving the Page Turning Problem in Musical Scores

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Abstract. *Musical scores remain essential in musical practice, yet manual page-turning can disrupt the flow and quality of collaborative performances. This paper presents eScore, a solution that automatically synchronizes digital scores between musicians and conductors to eliminate interruptions and enhance performance dynamics. Developed and evaluated in real-world scenarios, eScore proved effective in reducing disruptions, fostering integration, comfort, and focus among performers. Identified improvements include interface refinement and broader device compatibility. Overall, eScore emerges as an innovative and promising tool to modernize musical practice, offering meaningful advances in collaboration and group performance efficiency.*

1. Introduction

Music is widely recognized as one of the most universal languages, transcending cultural and temporal boundaries. From the early rudimentary notational systems of the Middle Ages, such as neumes, to the introduction of modern notation by Guido d'Arezzo in the 11th century, musical scores have played a vital role in the preservation and dissemination of musical knowledge [1]. By enabling the accurate representation of elements such as duration, rhythm, dynamics, and pitch, the musical score has evolved into a universal language. Musicians around the world can interpret written works without the need to speak the same language, allowing music to cross borders and eras. Furthermore, scores preserve the composer's original intent, fostering both emotional and historical connections to musical works.

Despite their historical and cultural significance, traditional printed scores present practical limitations. One of the most prominent challenges musicians face is the need to manually turn pages during performance. This action disrupts the musical flow during performance and may be particularly problematic during critical passages or collaborative settings, such as orchestral rehearsals and concerts [2]. The relevance of this issue has led to the development of various solutions over time. These include electronic page-turning pedals, synchronized apps, and advanced technologies such as eye-tracking. Interestingly, even the role of the human page-turner was created to address this challenge, a seemingly simple task that becomes essential in professional performances, highlighting the practical importance of the problem in musical contexts.

With the advent of digital technology, more practical alternatives have emerged, such as the use of tablets and e-readers, which offer benefits like portability, customizable annotations, and repertoire organization [3]. However, these approaches also bring new limitations, including the frequent need to turn pages due to limited screen size and barriers related to cost and accessibility. These challenges have inspired a wide range of studies and technological solutions aimed at overcoming the limitations of both physical and digital scores. A historical overview of such developments is presented in Section 2, which discusses related work and their contributions to the field. This study was motivated by the need to address the remaining gaps in existing solutions, particularly regarding page turning in digital scores. The proposed system, `eScore`, aims to integrate automatic synchronization with an intuitive interface, allowing musicians to focus entirely on performance.

Leveraging technologies such as network-based synchronization, `eScore` adopts a centralized and collaborative approach to overcome previous limitations. Preliminary results suggest that the system can significantly enhance fluency, group coordination, and overall performance quality. This paper evaluates its effectiveness in real-world contexts, focusing on usability and impact on musical practice.

2. Related Work

The issue of page turning in digital sheet music has been extensively investigated due to its practical relevance for musicians across various contexts. We conducted a systematic literature review using the following search string: `(Sheet OR Score) AND (Music OR Song) AND (Software OR App OR Tool OR System OR "computer-assisted")`, aiming for comprehensive coverage of relevant terms. The databases consulted included ACM, IEEE and ScienceDirect, selected for their recognized importance in the fields of computer science and music. The initial search yielded 772 studies. After applying inclusion and exclusion criteria, we discarded 748 studies and 16 identified as duplicates. In total, eight studies were

selected as relevant for analysis, forming a solid foundation for understanding the current state of solutions in the field[1].

Sound Recognition-Based Solutions: Chou *et al.* [4] proposed a mobile app that uses sound recognition to detect the current measure and turn pages automatically. Tested with pianists, violinists, and flutists, the system enabled uninterrupted performance. However, it showed limitations in noisy settings such as rehearsals and concerts, and in pieces with complex time signatures.

Eye-Tracking-Based Solutions: Bonnici *et al.* [5] introduced an integrated solution combining score flattening and eye-tracking to automate page turns. This approach detects the musician's gaze position and turns the page at the appropriate moment. While promising in reducing performance interruptions, the solution's high cost and dependency on specialized hardware hinder its accessibility for amateur musicians.

Hybrid and Adaptive Solutions: Hamanaka *et al.* [6] presented Aibiki, a hybrid solution combining audio recognition with adaptive automation tailored to the shamisen. While effective for specific musical styles, the system struggles to generalize across instruments and genres.

Hardware-Based Solutions: Iijima *et al.* [7] developed PEANUTS that synchronizes scores in ensembles but still requires a designated musician to trigger page turns. In contrast, `eScore` provides fully automated, centralized synchronization, removing the need for manual intervention and better supporting both ensemble and solo performances.

EOG and ZigBee-Based Solutions: [8] proposed an Electrooculography (EOG) solution for turning digital score pages by transmitting eye movement signals via ZigBee to an electronic score system. The approach offers full automation but requires specialized hardware and complex setup, limiting its practicality for casual or amateur use. The study also lacked detailed experimental documentation.

Other Approaches: Sung *et al.* [9] evaluated an interactive music stand with automatic view adjustments, annotations, and basic synchronization. Tested in academic and professional settings, it showed potential to reduce reliance on printed scores but depends on proprietary infrastructure, limiting its feasibility for smaller groups. EyeMusic [10] uses eye-tracking glasses to aid musical learning via auditory feedback. As users focus on score sections, the system plays corresponding notes. Though not intended for page turning, it may be adapted for such use. Limitations include hardware reliability and the need for pre-edited scores. Souza *et al.* [11] introduced a weightless neural network to predict page turns based on musical patterns. While promising, it remains in early stages and faces challenges like adaptation to different styles and computational demands. These solutions offer diverse strategies to address digital page turning. However, technical, financial, and scalability barriers persist. `eScore` builds on these advances as an accessible, scalable alternative for enhancing musical performance across varied contexts.

[1]The complete dataset from this systematic review, including the analyzed and selected studies, is available on Zenodo at DOI `https://doi.org/10.5281/zenodo.15777531`

3. Methodology

We followed a systematic design consisting of four main stages: software development, experimental evaluation planning, execution, and analysis. This structured approach ensured a logical and progressive transition between phases, enabling continuous system refinement and validation under real-world conditions.

3.1. eScore Development

The development of `eScore` was carried out using agile methodologies, emphasizing incremental deliveries and the incorporation of iterative feedback. This approach ensured flexibility throughout the development process, allowing for rapid and continuous adjustments based on testing and validation results.

3.1.1. Software Requirements

We identified and categorized the software requirements into functional and non-functional. These requirements are essential for ensuring the functionality and quality of the digital score application with real-time synchronization. Functional requirements define the core capabilities the system must provide to meet musicians' needs. They establish the software's operational features, such as score loading, real-time synchronization, progress bar display, and seamless navigation. The prioritization of these requirements was guided by the system's key aspects, particularly those ensuring core functionalities, such as real-time synchronization and score rendering. Table 1 presents the identified functional requirements, classified by priority and implementation status.

Table 1: Functional Software Requirements

ID	Requirement	Pr.	St.
FR1	Upload of digital sheet music: The system must allow uploading scores in MusicXML and XML formats.	H	I
FR2	Real-time synchronization: Synchronization between conductor and musicians during performance.	H	I
FR3	Real-time progress bar: Continuous update of score position according to the musical tempo.	H	I
FR4	Intuitive navigation in the score: Allow fast and fluid navigation without compromising synchronization.	M	I

Legend: Pr.-Priority | St.-Status | H-High | M-Medium | I-Implemented

Non-functional requirements define attributes that influence the system's quality, performance, and accessibility. They ensure that the

application is reliable, user-friendly, compatible with various devices and file formats, and accessible to all users. Table 2 presents the non-functional requirements, along with their priorities and implementation status.

Table 2: Non-Functional Software Requirements

ID	Requirement	Pr.	St.
NFR1	Usability: Intuitive and user-friendly interface for musicians.	H	I
NFR2	Performance: Fast response in updating the progress bar position.	H	I
NFR3	Reliability: Ensure stability during musical performance.	H	I
NFR4	Portability: Compatible with multiple devices and operating systems.	M	I
NFR5	Compatibility: Support for various digital score formats.	M	I
NFR6	Accessibility: Features such as zoom, adjustable contrast, and reduced animations.	M	P

Legend: Pr.-Priority | St.-Status | H-High | M-Medium | I-Implemented | P-Partially Implemented

In the case of NFR6, the zoom functionality has been successfully implemented; however, features related to contrast adjustment and animation reduction have not yet been developed. These aspects remain pending for future system versions. The tables provide a clear overview of the current implementation status of the system requirements, supporting monitoring and prioritization of future improvements.

3.1.2. Technologies and Architecture

The `eScore` project was designed following a modular architecture, separating responsibilities into logical layers to facilitate system maintenance and future evolution. The main technologies adopted and their roles in the system are described below: (i) **OpenSheetMusicDisplay (OSMD)**: For rendering sheet music in the *MusicXML* format, the *OpenSheetMusicDisplay* library was employed [12]. This choice enabled clear and accurate score visualization with support for complex musical notation; (ii) **WebSockets (Socket.IO)**: To enable real-time communication between conductor and musicians, the *Socket.IO* framework was used [13], offering low latency and reliable message transmission; (iii) **TypeScript**: The system was developed using *TypeScript* [14], a statically typed language that enhances code robustness by enabling early detection of errors; (iv) **Next.js**: The user interface was implemented using *Next.js* [15], which provides scalability, optimized performance, and flexibility for building modern web applications. The development of `eScore` followed an integrated approach, leveraging the native capabilities of the Next.js framework to combine both front-end and backend within a unified environment. This decision simplified the system architecture by eliminating the need for a separate backend, while still fulfilling the project's requirements.

3.1.3. Internal Validation and Refinement

Following the development of the first functional prototype, internal testing was conducted to validate the system's core features. These tests were based on real usage scenarios and prioritized aspects such as: (i) Real-time synchronization between conductor and musicians; (ii) Interface responsiveness and performance; (iii) Ability to process complex sheet music. The outcomes of these tests guided system improvements, including latency adjustments in real-time communication and optimizations in score loading and rendering.

3.1.4. Application of Agile Methodologies

The adoption of Agile Manifesto principles played a key role in guiding the development process. Deliveries were organized into two-week sprints, each focusing on specific features such as score loading or WebSocket integration. At the end of each sprint, the system underwent internal validation, enabling rapid and effective iterations [16].

3.1.5. Developed Solution

The solution developed for `eScore` successfully implements the previously defined and validated requirements, offering an optimized experience for both conductors and musicians. The system was designed to enhance the efficiency of rehearsals and musical performances, promoting integration and personalization through advanced technological features, as illustrated in Figures 1 and 2.

The conductor has access to a centralized interface that provides full control over score execution and synchronization. This interface includes advanced tools such as: (i) **Playback and tempo control**: Enables the conductor to start, pause, and adjust the tempo in real time. Any tempo changes are automatically synchronized with all connected musicians; (ii) **Full score view**: Displays all instrumental parts simultaneously, facilitating ensemble supervision and coordination; (iii) **Individual conductor settings**: Allows fine-grained control over zoom and volume by instrument, enabling detailed customization to support the conductor's specific needs during performance; (iv) **Seamless synchronization**: Offers advanced navigation tools with visual markers that indicate the current position in the score, ensuring perfect alignment between conductor and musicians.

Each musician is provided with a personalized interface, synchronized with the conductor, featuring: (i) **Instrument selection**: The app allows each musician to select their instrument and view only the corresponding part. When a .mxl or .xml score is uploaded, the system reads the list of instruments embedded in the file and matches them to the musician's selection, displaying only that part. Currently, scores are uploaded manually by the administrator, and there is no option for users to import their own scores yet — this feature is planned for future versions; (ii) **Individual controls for playback,**

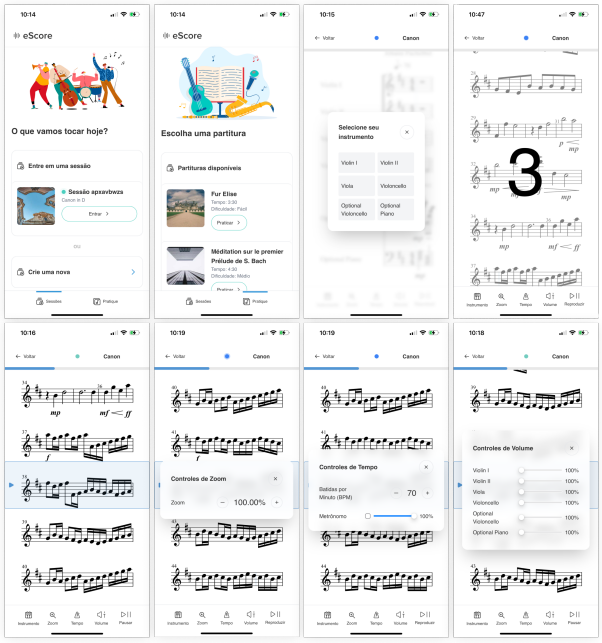

Figure 1: Musician's View

volume, and tempo (Beats Per Minute - BPM): Musicians can control playback of their own part, adjust volume, and modify the tempo while the session is paused—supporting focused practice and clarification of specific measures; (iii) **Quick instrument switching**: Enables musicians to easily switch between instruments when needed, offering flexibility during rehearsals; (iv) **Automatic synchronization with visual feedback**: The interface reflects the conductor's actions in real time, displaying the current position in the score with clear visual markers; (v) **Zoom customization**: Provides individual zoom control for comfortable reading tailored to the musician's preferences.

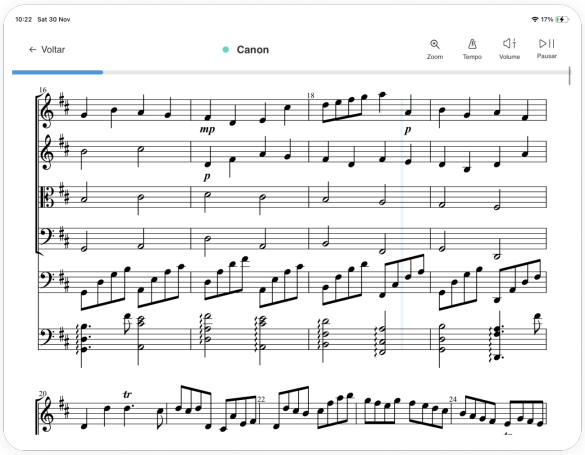

Figure 2: Conductor View

The interface centralizes control in the conductor, who coordinates execution with precision, while musicians retain autonomy to adjust individual elements without disrupting the overall performance. Automatic synchronization eliminates tempo discrepancies, enabling all participants to follow the conductor's pacing. At the same time, features such as playback control, zoom, and volume adjustments provide comfort and personalization.

The solution also fosters a smooth and collaborative reading experience through an intuitive and adaptable interface, strengthening alignment between conductor and musicians. Centralized tools for the conductor and customizable features for performers make rehearsals more productive by reducing interruptions and optimizing the time dedicated to musical interpretation. Furthermore, real-time communication enabled by WebSockets ensures that any changes made by the conductor are instantly propagated to all connected musicians' devices, preserving cohesion throughout the performance. For greater flexibility, the system allows sessions to be paused, giving musicians the opportunity to individually adjust playback, volume, and timing, supporting detailed review of specific passages without compromising the overall rehearsal flow.

3.2. Experimental Evaluation Planning

The experimental evaluation was designed to assess the effectiveness and usability of `eScore` under real-world conditions, allowing for direct comparisons with traditional methods. Two group sessions were conducted for this purpose: (i) **One session using physical sheet music (traditional method)**; (ii) **One session using the `eScore` system**.

We selected the piece Canon in D Major by Johann Pachelbel as the experimental material due to its collaborative structure, which enables clear and accurate testing of synchronization between conductor and musicians. The sessions were conducted in a controlled environment using a locally configured local area network (LAN). For the MVP tests, the server was run locally on the conductor's computer and exposed to the local network. Musicians connected to the application by accessing the local server's IP address while on the same Wi-Fi network. Currently, eScore operates exclusively on a local network, eliminating the need for internet connectivity. A future release will support deployment on a public server, enabling remote rehearsals. The participant group consisted of three string musicians, aged between 22 and 34, with varying levels of familiarity with digital sheet music. During the tests, the researcher acted as conductor, responsible exclusively for starting and pausing playback, while the musicians interacted directly with the scores. This setup enabled the system to be evaluated in a collaborative scenario, focusing on both coordination and the usability of the proposed features.

3.3. Execution of Experimental Evaluation

During the experimental sessions, participants completed both of the planned approaches. Each session was observed by facilitators who recorded spontaneous interactions and participant behavior while using both methods. Data collection focused on three key aspects: (i) Real-time synchronization accuracy; (ii) Ease of navigation and interface usage, and; (iii) Impact on the fluidity of musical execution. The sessions were designed to provide an immersive and realistic experience, replicating typical rehearsal or performance scenarios.

3.4. Data Collection

Data collection combined quantitative and qualitative methods to comprehensively explore the musicians' experience. The process included the following stages: (i) **Pre-Test Forms:** Gathered information about participants' profiles, previous experience, and expectations regarding digital sheet music; (ii) **Post-Test Forms:** Using the System Usability Scale (SUS) [17] and Technology Acceptance Model (TAM) [18]); (iii) **Focus Group Sessions:** Enabled open-ended discussions about the experience, generating complementary qualitative insights.

Focus group sessions were conducted with flexibility, following the approach of Krueger and Casey [19], to capture spontaneous perceptions of the `eScore` system. Conversations were guided by a few initial prompts and conducted in an open manner, allowing participants to express both technical and emotional perspectives. All sessions were recorded, transcribed, and analyzed to identify patterns, challenges, and suggestions for improvement. This feedback was then used to guide refinements to the system and enhance the overall user experience.

3.4.1. Structure of Forms

We designed the pre-test forms to gather information about participants' profiles, focusing on their familiarity and experience with digital sheet music. The post-test forms aimed to evaluate the usability and technological acceptance of `eScore`. We designed specific questions to measure ease of use, efficiency, and the system's impact on the musical experience.

3.5. Data Analysis

We analyzed the collected data using an integrated approach, combining both quantitative and qualitative methods: (i) **Quantitative:** We conducted statistical analyses based on the SUS and TAM models, measuring system usability and acceptance; (ii) **Qualitative:** We thematically organized transcripts from the focus group sessions, highlighting strengths, limitations, and suggestions for improvement. The triangulation of quantitative and qualitative methods enabled validation of the findings, identifying the system's main strengths and areas for enhancement.

3.6. eScore Assessment

The validation of `eScore` was based on both objective and subjective criteria: (i) **Real-Time Synchronization:** Assessed during the experimental sessions, ensuring page turns occurred without perceptible delays; (ii) **Ease of Use:** Praised by participants, particularly for its responsive and intuitive interface; (iii) **Impact on Musical Flow:** Observed during performances and confirmed in participant feedback, which reported improved focus and fewer interruptions. The results indicate that `eScore` successfully met the study's objectives and was recognized as a practical and innovative solution for musicians. Suggestions raised during the evaluation will be incorporated into future iterations, ensuring continuous system improvement.

4. Results

We organized the results to provide a comprehensive overview of `eScore`'s effectiveness in musical practice. Data were collected through pre- and post-test questionnaires, as well as focus group sessions, which offered detailed qualitative insights into participants' experiences. To support a structured analysis, the SUS and TAM models were employed. These frameworks enabled objective measurement of system usability and technological acceptance, complementing the qualitative data obtained.

4.1. Participant Profile

Participants were string musicians, including performers of violin, second violin, and cello, with ages ranging from 22 to 34 years. Most participants identified themselves as having intermediate musical skills and reported moderate familiarity with the use of digital sheet music. This diversity of backgrounds was important for evaluating `eScore`'s adaptability across different contexts and levels of experience. Table 3 presents the demographic and technological familiarity data. It is worth noting that the average familiarity with digital score reading was 3.0 on a scale from 1 to 5, indicating a heterogeneous group.

Table 3: Participant Profile

Feature	Avg.	Min.	Max.
Age (years)	28,5	22	34
Familiarity with reading digital sheet music (Scale 1-5)	3	1	5
Instruments	Violin and Cello		

4.2. Quantitative Results

The quantitative data obtained from the post-test questionnaires demonstrate the effectiveness of `eScore` in musical practice. We conducted the analysis using the SUS and TAM models, along with additional direct metrics captured through the questionnaire. The results were broadly positive, indicating high usability and strong technological acceptance.

4.2.1. SUS Results

We conducted a usability evaluation of the system using the System Usability Scale (SUS), a widely recognized method for assessing the usability of technological systems. eScore achieved an average score of 96.67 on a scale from 0 to 100, as detailed in Table 4. This result is significantly above the commonly accepted benchmark of 68, which is generally considered the threshold for acceptable usability [17], indicating that the system was perceived as highly intuitive and easy to use by participants. Moreover, the consistency of individual ratings was notable: the lowest score recorded was 95.0, and the highest was 97.5, reinforcing the strong positive perception of eScore's usability. These findings suggest that the system meets user expectations and provides a smooth and efficient user experience.

Table 4: SUS Results

SUS Metrics	Value
Average Score	96.67
Minimum Score Observed	95.00
Maximum Score Observed	97.50

The results highlight the system's high usability, with only minor issues reported—such as occasional synchronization glitches and challenges with playback control. These observations can guide future improvements to eScore, ensuring an even more satisfying user experience. [20] introduced an online analysis tool specifically designed for SUS assessments. This tool simplifies the calculation of SUS scores, median values, response distributions, and other key metrics. Figure 3 presents the SUS scale as applied to eScore. The overall SUS score of 96.67 places the system in the "Best Imaginable" category and with an "Acceptable" level of accessibility.

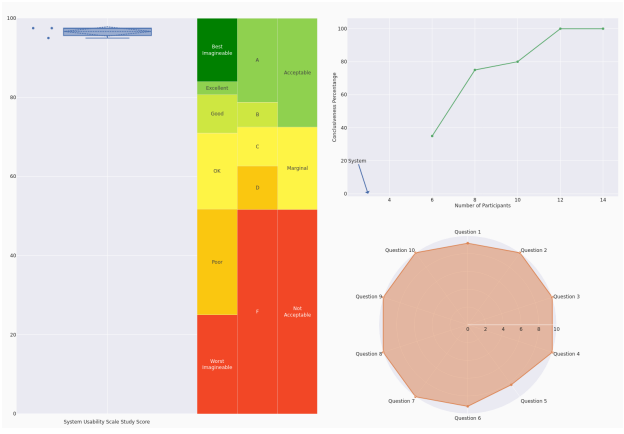

Figure 3: SUS Results

4.2.2. TAM Results

We used the TAM [18] to evaluate the technological acceptance of eScore, focusing on two main constructs: (1) Perceived Ease of Use (PEoU), and (2) Perceived Usefulness (PU).

The results show that PEoU achieved an average score of 4.92 on a 1-to-5 scale, indicating a very positive perception regarding the system's ease of use. PU reached an average score of 4.61, with responses ranging from 3.0 to 5.0, in Figure 4. These results suggest that eScore is widely regarded as useful for musical activities such as score reading and performance. The PEoU metric received high scores, indicating that users found eScore intuitive and easy to operate. Similarly, the PU metric also stood out, reflecting the value of eScore in enhancing efficiency and accuracy in score reading and performance.

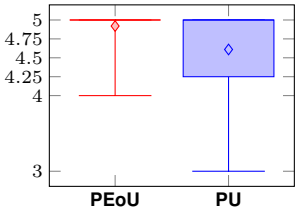

Figure 4: Descriptive analysis of TAM results.

4.2.3. Other Quantitative Metrics

In addition to the SUS and TAM models, the post-test questionnaire captured additional perceptions of eScore, further reinforcing the participants' overall positive experience. Ease of Navigation (EN) system was rated as "easy" by all respondents, with an average score of 5.0. Synchronization Accuracy (SA) was evaluated as "accurate" to "very accurate", reaching an average of 4.33, with scores ranging from 3.0 to 5.0. Other relevant metrics were also recorded and are detailed in Figure 5. The Practice and Performance Quality (PPQ) metric received an average score of 4.67, highlighting the positive impact of eScore on the overall experience of musicians. However, the Future Usage Intent (FUI), while still positive with an average of 4.33, suggests that some participants may have perceived potential limitations regarding long-term adoption of the system.

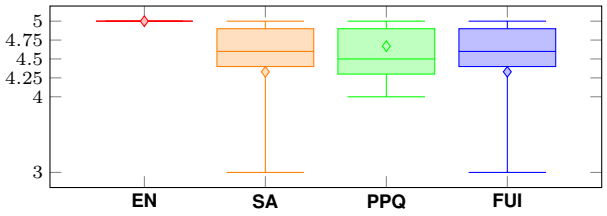

Figure 5: Descriptive Analysis of Other Metrics.

These data complement the SUS and TAM results, providing a more comprehensive view of the musicians' experience with eScore. The unanimous rating of ease of navigation reflects the system's high intuitiveness, while the high average scores for synchronization accuracy and practice quality reinforce eScore's effectiveness in meeting musicians' needs.

4.2.4. Main Results Identified

Synchronization Accuracy: The automatic synchronization feature was widely praised and consid-

ered essential for cohesion during rehearsals and performances. Musicians reported satisfactory performance even in pieces with varying time signatures: “This piece is different in that the measures I’m playing don’t match in numbering with others. And it synced everything perfectly... I thought it would glitch, but it didn’t” (Violinist 2).

Follow Cursor: The cursor was regarded as helpful for guiding the musicians, but some participants noted discomfort due to its constant movement—particularly during slower passages. A suggestion was made for the cursor to remain fixed on the current note and only move when the next one begins: “The pointer keeps moving. The note is two beats long, and the pointer keeps going. Why not just have the pointer stop at the note and only jump to the next?” (Violinist 2).

Accessibility and Usability on Mobile Devices: Adaptability on mobile devices was highlighted as one of `eScore`’s most positive aspects. Even when used on smartphones, the interface maintained its functionality without compromising the experience: “I played in portrait mode. Just like that. It worked just fine... I had two measures per line and played the whole piece without issues” (Violinist 2).

Visibility of Upcoming Staves: Some participants reported difficulty previewing the next staff line. We considered the lack of visibility detrimental to performance flow: “One thing that can’t happen in your app is having the current staff visible but the next one hidden. Before it changes, it needs to already be visible below” (Violinist 2).

4.3. Discussion of Results

The results indicate that `eScore` was well received by the participants, with particular emphasis on its high usability and synchronization accuracy. The high SUS score and the positive TAM results confirm that the system meets usability and technological acceptance criteria, demonstrating its potential to transform how musicians interact with digital sheet music. Focus group sessions provided valuable insights into the system’s impact on musical practice. The ability to synchronize sheet music in real time was highlighted as a key feature, especially in complex pieces with varying time signatures. However, the continuous movement of the cursor was identified as an aspect requiring attention, representing an area for improvement in future versions of `eScore`.

The system’s flexibility across different devices was also widely praised. The ability to use `eScore` on smartphones without compromising the musical experience expands its reach, making it an accessible solution for both professional and amateur musicians. These results reinforce the relevance of `eScore` as an innovative tool for musicians while also pointing to clear directions for its improvement.

5. Final Remarks

This study aimed to develop and evaluate `eScore`, an innovative application for digital sheet music reading that integrates automatic synchronization between musicians and the conductor. From its inception, the project sought to overcome the limitations of traditional physical and digital sheet music by offering a practical, efficient, and collaborative solution. Through a structured methodology, development phases, controlled experimental tests, and both qualitative and quantitative analyses were conducted to validate the system.

The results demonstrated that `eScore` achieved the proposed objectives, standing out for its efficiency, usability, and technological acceptance. The average SUS score of **96.67** highlighted the system’s high usability, while the TAM results indicated strong acceptance among participants. Features such as real-time synchronization accuracy and an intuitive interface were noted as key differentiators, making `eScore` an accessible and practical tool for musicians of varying experience levels.

Based on the results and participant feedback, several directions for improvement and expansion of `eScore` were identified: (i) **Refinement of the Follow Cursor:** Implementing a more intuitive behavior, such as keeping the cursor fixed on long notes, could enhance the visual experience and reduce musicians’ anxiety during performances; (ii) **Sample Expansion**: Including musicians from diverse ensembles, instruments, and varying levels of technological familiarity to better assess generalizability; (iii) **Repertoire Complexity**: Future tests should incorporate pieces with complex structures, frequent repetitions, and varied sections that require constant navigation, thereby increasing the system’s challenge and the need for page turns; (iv) **Educational Integration:** Expanding `eScore` to musical education platforms and rehearsal management tools, making it an essential solution in educational environments; (v) **Technical Optimization:** Improving performance on lower-capacity devices through memory and processing optimizations to ensure universal accessibility; (vi) **Testing in Adverse Scenarios:** Conducting evaluations under challenging conditions, such as environments with limited connectivity, to validate the system in adverse contexts. These enhancements have the potential to consolidate `eScore` as a robust and widely adopted tool, significantly impacting the way musicians interact with digital sheet music.

This study represents a significant contribution to the application of technology in music. Compared to existing tools such as Forscore and Newzik, `eScore` distinguishes itself by providing real-time conductor-to-musician synchronization over a network, rather than relying on individual musician page-

turning or pedal systems. While Forscore and Newzik offer annotation and organization features, they do not natively centralize tempo and score progression control in the conductor, which is a key differentiator of eScore.

Moreover, this work establishes an initial milestone for the development of new technological tools in the field of music. By combining automatic synchronization with an intuitive interface, `eScore` demonstrates how innovative technologies can transform the interaction between musicians and digital sheet music, promoting efficiency and practicality in collaborative contexts. It also shows potential to influence the digital sheet music market, positioning itself as a promising and accessible alternative.

The development of `eScore` represents a significant advancement in the application of digital technologies in music by proposing a solution that combines innovation, simplicity, and effectiveness. This work has demonstrated the potential of `eScore` to transform musical practice, promoting an integrated and seamless experience for musicians and conductors. Future prospects, combined with the proposed improvements, position `eScore` as a reference in the digital sheet music market. Its impact goes beyond technology, contributing to the evolution of musical practice and inspiring the development of new solutions that connect technology and art. Thus, `eScore` reaffirms the role of innovation as an ally in advancing music as a universal form of expression.

We have recently released an upgraded version of `eScore`, now titled `BandSync`, which is available for download at `http://bandsync.io`. BandSync is currently offered as a free solution, however, we plan to adopt a Freemium model in the future by introducing a subscription system that will provide additional premium features while maintaining a free basic tier.

References

[1] Guitarpedia. O que é partitura? seus primeiros passos para leitura dela. `https://blog.guitarpedia.com.br/o-que-e-partitura-seus-primeiros-passos-para-leitura-dela/`. Acessado em: 07/03/2022, jan 2020.

[2] Jane Borges. Partitura musical: um instrumento de investigação em história da educação. In *Anais do XVI Congresso da Associação Nacional de Pesquisa e Pós-graduação em Música, Brasília*, 2006.

[3] Wen-Tsai Sung, Jui-Ho Chen, and Kuo-Yi Chang. Zigbee based multi-purpose electronic score design and implementation using eog. *Sensors and Actuators A: Physical*, 190:141–152, 2013.

[4] Po-Wen Chou, Fu-Neng Lin, Keh-Ning Chang, and Herng-Yow Chen. A simple score following system for music ensembles using chroma and dynamic time warping. In *Proc. of the 2018 ACM on International Conference on Multimedia Retrieval*, page 529–532, 2018, 2018. ICMR '18.

[5] Alexandra Bonnici, Stefania Cristina, and Kenneth P. Camilleri. Preparation of music scores to enable hands-free page turning based on eye-gaze tracking. In *Proc. of the 2017 ACM Symposium on Document Engineering*, page 201–210, 2017, 2017. DocEng '17.

[6] Takahito Hamanaka, Daisuke Sakamoto, and Takeo Igarashi. Aibiki: Supporting shamisen practice with adaptive automatic score scroll. In *Proc. of the 11th Conference on Advances in Computer Entertainment Technology*, ACE '14, New York, NY, USA, 2014. Association for Computing Machinery.

[7] Yasue Iijima, Shigeru Fujita, and Susumu Konno. Proposal of algorithm for designating the person in charge of page turn of peanuts considering the concert program. In *2016 10th International Conference on Complex, Intelligent, and Software Intensive Systems (CISIS)*, pages 337–340, 2016.

[8] Wen-Tsai Sung, Jui-Ho Chen, and Kuo-Yi Chang. Zigbee based multi-purpose electronic score design and implementation using eog. *Sensors and Actuators A: Physical*, 190:141–152, 2013.

[9] J. Kosakaya, Y. Takii, M. Kizaki, A. Esashi, and T. Kiryu. Research and evaluation of a performer-friendly electronic music stand. In *Proc. of the 2005 International Conference on Active Media Technology, 2005. (AMT 2005).*, pages 11–15, 2005, 2005.

[10] Qinjie Ju, René Chalon, and Stéphane Derrode. Assisted music score reading using fixed-gaze head movement: Empirical experiment and design implications. *Proc. ACM Hum.-Comput. Interact.*, 3, 2019.

[11] Diego F. P. De Souza, Felipe M.G. Franca, and Priscila M.V. Lima. Real-time music tracking based on a weightless neural network. In *Proc. of the 9th Int. Conf. on Complex, Intelligent, and Software Intensive Systems*, pages 64–69, 2015.

[12] Open Sheet Music Display. `https://github.com/opensheetmusicdisplay/opensheetmusicdisplay`, 2023. Accessed: 2024-11-24.

[13] Socket.IO. Socket.IO Documentation. `https://socket.io`, 2023. Accessed: 2024-11-24.

[14] Microsoft Corporation. *TypeScript Documentation*, 2023. Accessed: 2024-11-24.

[15] Vercel. *Next.js Documentation*, 2023. Accessed: 2024-11-24.

[16] Kent Beck and *et al.* Manifesto for agile software development. `https://agilemanifesto.org`, 2001. Accessed: 2024-11-24.

[17] John Brooke. Sus: a "quick and dirty" usability scale. *Usability Evaluation in Industry*, 189:4–7, 1996.

[18] Fred D. Davis. *Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology*, volume 13. University of Minnesota, 1989.

[19] Richard A. Krueger and Mary Anne Casey. *Focus Groups: A Practical Guide for Applied Research*. SAGE Publications, Thousand Oaks, 5 edition, 2015.

[20] Jonas Blattgerste, Jan Behrends, and Thies Pfeiffer. A web-based analysis toolkit for the system usability scale. In *15th Int. Conf. on PErvasive Technologies Related to Assistive Environments*, pages 237—-246, New York, NY, USA, 2022. ACM.