Multimedia Tools and Applications
https://doi.org/10.1007/s11042-025-20637-0

Music dynamics visualization for music practice and education

Eun Ji Park[1]

Received: 12 October 2022 / Revised: 19 September 2024 / Accepted: 14 January 2025

Abstract
Currently, musicians rely on their sense of hearing and notation cues on sheet music to precisely perform musical dynamics. However, other tools can help visualize music dynamics efficiently and enable musicians to create, emulate, and perform more effectively. Accordingly, we developed a Musical Dynamics Visualization Method (MDVM) interface program to visualize the amplitude of both a pre-recorded track and the real-time sound of the user playing the score. The interface layers the recorded visuals over real-time visuals to help the player precisely replicate the intended sound. The interface was developed for solo performances to allow them to carefully focus on amplitude changes. This novel MDVM method demonstrated impressive effectiveness in enhancing the expression of musical dynamics. Specifically, it reduced musical dynamic errors by approximately 256%, enhanced music education, and deepened students' emotional engagement. This method, thus, contributes to a more holistic and effective learning experience through its exceptional outcomes.

Keywords Amplitude change · Amplitude visualization · Musical dynamics · Musical expression · Musical education · Music practice tool

1 Introduction

Dynamics are one of the most crucial aspects of music. The loudness or softness with which a note or passage is played can drastically affect the mood and emotional quality of the piece [1]. The effects of expressive variation in dynamics considerably influence a listener's emotions and cognition, as different interpretations of a piece's dynamics can evoke varied responses [2]. Given the importance of musical dynamics, particularly in music practice and education, this research aimed to investigate how computer-aided learning, using visualization tools, impacts music practice and education, with a special focus on dynamics.

✉ Eun Ji Park
dr.rosyrosys@gmail.com

1 Department of Musicology, Seoul National University, Seoul, South Korea

In traditional Western music notation, performers rely on subjective markings in the score to determine how loudly or softly to play [3]. However, these markings present limitations, particularly for those who are not professional musicians, in expressing the appropriate dynamics for a piece with precision. These traditional dynamic indications provide relative, rather than absolute, guidelines, which can lead to variations in interpretation among different performers [4]. This variation poses a risk of not conveying the composer's intended dynamics consistently. Particularly, non-professional musicians often need more effective guidance to properly understand and express the dynamics intended by the composer. Traditional music education has primarily relied on verbal explanations or abstract examples of performances to convey these dynamics [5], which may not always provide the concrete support that less experienced musicians require.

The MDVM, which we have developed for the first time, converts auditory information into visual cues, allowing users to detect subtle dynamic variations that may be difficult to perceive by ear. This interface visualizes live audio performances in real-time and supports comparison with pre-recorded track visualizations, enabling musicians to analyze and refine their dynamics by comparing them with exemplary performances.

Designed for use by musicians of all levels, from professionals to amateurs and even children, MDVM is a versatile tool that can be effectively utilized in both individual practice and educational settings. One common challenge musicians face is the difficulty of accurately hearing their own sound or external sources during a performance. While traditional recording devices offer some assistance, the MDVM provides additional functionality by measuring dynamics, a crucial element of musical expression, and allowing real-time comparison with sheet music. The MDVM enables musicians to visually compare their performances with recordings of others or themselves, revealing subtle details in amplitude changes that may be missed by the ear alone.

The core idea of MDVM is rooted in the concept of imitation. Whereas traditional methods focus on auditory imitation, this interface transforms sound into visual representations, allowing students to imitate these visual cues. In traditional educational methods, imitation has always been essential to learning. Importantly, this principle can now be approached more effectively through modern technology.

In experiments using various configurations, the MDVM demonstrated a critical improvement in students' musical accuracy, particularly in their expression of dynamics, with the effectiveness of dynamic visualization being especially prominent in educational settings. For example, in the formal tests, students' dynamic error rates were reduced by approximately 256%, after utilizing MDVM. These results confirm that the MDVM offers superior efficiency and outcomes in music practice and education compared to traditional methods.

Therefore, the MDVM is an innovative tool that enhances musicians' ability to visually comprehend and express dynamics, thereby improving their appropriate dynamic expression in performances and emotional articulations. Owing to its educational effectiveness, MDVM proves to be a valuable resource not only for individual practice but also in formal music education settings. The contributions of this study can be summarized as follows:

1) *Integration of traditional notation with modern visualization techniques*: We successfully integrated traditional Western music notation, which has been in use since the seventeenth century, with modern visualization techniques by developing the MDVM. This integration not only preserves the pedagogical value of traditional notation but

also enhances it by providing musicians with an advanced tool to better understand and interpret dynamics in a visual format.
2) *Advancement of music practice and education*: Our approach has proven effective in dynamic education by enabling the overlay of dynamic visualizations derived from teacher recordings with those of students, thereby advancing music practice and education. This method provides musicians with clear and detailed insights into the dynamic choices made by expert performers, allowing them to refine their techniques and achieve an expressiveness level difficult to attain through auditory feedback alone.
3) *Quantification of emotional characteristics*: The data used in our experiments were derived from real-world performances, not artificial data, reflecting our pioneering effort to quantify the unique emotional characteristics of performers—a challenge that has not been previously addressed using this approach.
4) *Bridging the gap between teachers and students*: By leveraging the MDVM to highlight differences in dynamic expression between teachers and students, this tool enables students to identify and address their weaknesses, thereby offering a more effective and accessible approach to mastering musical dynamics. This study specifically focused on this aspect, validating the educational value of MDVM through targeted experiments that demonstrate its efficacy.

In summary, the contributions of this study lie in the innovative combination of traditional techniques with modern technologies, the advancement of performance practice, the enhancement of educational resources, and the facilitation of a deeper understanding of musical dynamics for both musicians and students. These advancements are expected to have a lasting impact on the field of music education and performance.

The remainder of this paper is organized as follows. Section 2 describes related works. Section 3 explains the background of this study. Section 4 presents the MDVM. Section 5 explains the experimental results. Section 6 elaborates on the limitations and future work. Finally, Sect. 7 concludes the paper.

2 Related works

This section provides foundational information to facilitate the understanding of the proposed MDVM. Music visualization has been widely investigated for various purposes. The related research can be categorized as follows: *music visualization for various musical elements*, *music visualization for dynamics*, and *music visualization for dynamics in education*. Among these, *music visualization for musical elements* can be further subdivided into *visualization of musical pitch* and *visualization of musical rhythm*, *tempo, and beat*. The relevant studies within these categories are as follows.

1) *Music Visualization for Various Musical Elements*: The representative studies on the visualization of musical pitch are works by McLeod and Wyvill [6], who introduced the use of Sing & See, a software that provides visual feedback for singing training through voice analysis. This software accurately shows a musician the pitch of the notes in any instrument, in real-time. McLeod and Wyvill created it to use as a teaching aid for beginners and for studying referents of sound production. Related applications include Notes!—Learn To Read Music (2013) by Visions Encoded Inc., Erol Singer's Studio—Voice Lessons (2014) by Erol Studios, and Sing-in Tuna (2014) by Hot Paw

Productions. Regarding *visualization of musical rhythm*, *tempo, and beat,* Alexander [7] investigated the visualization of beat and tempo, two fundamental components of music that have been relatively underexplored in research. Some related applications are BPM (Beats Per Minute)-Detector by Sandberg Sound (2013), Live BPM–Beat Detector by Daniel Bach (2013), and BPM counter free by Microbull Software (2013). Recent research on Music Visualization has been limited, with the most recent survey paper on the topic being published in 2022 [8].

2) Music visualization for dynamics: The representative research on *visualization for dynamics* includes Langner et al., Krumhansl, and Berndt and Hähnel [9–11]. Langner et al. utilized a recording program called "Dynagrams" to visualize musical dynamics, where more significant changes in dynamics were depicted using stronger and more vibrant colors [9]. Upon examining the differences in dynamic expression between professional and nonprofessional performers, Langner et al. observed that the colors associated with professional performers were clearer and more distinct [9]. Krumhansl investigated the relationship between the dynamic aspects of musical emotion and the cognition of musical structure through visualization. His study revealed that performances by non-professionals exhibited weaker and paler colors compared to performances of professionals, creating a visually striking contrast. In the visualizations, different colors represented different meanings, and the dynamic shaping effectively reflected the formal structure of the composition [10]. Additionally, Berndt and Hähnel [11] developed models to describe and recreate musical dynamics properties of human musicians' expressive performances within a performance system.

3) Music visualization for dynamics in education: Percival [12] developed a computer-assisted musical instrument tutoring system known as MEAWS (Multimedia-Enhanced Automated Web-based System), which incorporates various methods of practice such as rhythmic exercises, rhythm grading, intonation detection, intonation grading, rhythm games, violin intonation games, and dynamics detection shapes [12, 13]. These authors explored the effective use of multimedia within MEAWS. The MEAWS system is particularly comparable to our MDVM, as it integrates elements of visualization with dynamics and education. MEAWS offers dynamic detection shapes for performance analysis, with its educational concepts and amplitude shape visualizations aligning closely with our research focus. However, the processes and educational methodologies employed in MEAWS differ from ours. While MEAWS includes components closely related to our work, especially in the areas of music education visualization and musical dynamics, its approach to visualizing dynamics was found to be somewhat inefficient and insufficiently intuitive for educational purposes. Additionally, the system lacks processes for comparison, preservation, experimentation, effectiveness, and verification.

Despite the development of numerous music visualization studies, research incorporating effective imitation and educational methods specifically for dynamics has not yet been fully realized. While previous studies have made critical contributions to music visualization and computer-assisted learning tools, space for improvement remains.

Although various musical elements have been visualized, the application of visualization techniques to the dynamics in music education has been insufficiently explored. Furthermore, existing tools have primarily focused on enhancing practice efficiency and accuracy, often neglecting the integration of traditional classical music elements. Building on these limitations, we have developed the MDVM that maintains the authenticity of classical music while leveraging modern visualization techniques to more effectively support musicians in the practice and education of dynamics. Therefore, we argue for the necessity of an effective visualization method, MDVM, specifically designed for musical dynamics. Through this newly developed MDVM, we pioneer the development of a visualization system that effectively functions as an educational tool, moving beyond traditional classical music education and conventional methodologies.

3 Background

This section discusses the importance of dynamics in music to facilitate the understanding of the proposed MDVM concept.

3.1 The importance of dynamics

Dynamics impart color and mood to music, evoking a range of emotions. Composers and performers employ musical dynamics to convey various meanings within a piece, manipulating the amplitude of sound to achieve this effect. Traditionally, this process involves learning through direct instruction from music teachers, utilizing notations inscribed by the composer on the music score.

For instance, traditional Western musical notation includes subjective markings that guide performers on how loudly or softly to play each passage. These markings, which have evolved since the seventeenth century, represent relative rather than absolute volume levels. This allows performers to interpret the musical dynamics in a manner that best conveys the intended emotion of the piece (Table 1).

However, traditional notations often provide only vague indications of the desired sound intensity. Historically, music education has relied on these conventional dynamic letters, where students learn dynamics through direct imitation of their instructor's performance during lessons. In response, we propose a visual representation of musical dynamics that allows students to observe amplitude changes and intuitively mimic them. This approach enables students to visually monitor and adjust their own amplitude changes during practice. Compared to traditional methods, which often rely heavily on direct teacher–student interactions and can be ambiguous, this method offers a more effective alternative for learning dynamics. By visualizing dynamics, students can engage in a more efficient

Table 1 Dynamic markings used in classical music since the seventeenth century

Name	Letters	Level
Fortississimo	***fff***	Very very loud
Fortissimo	***ff***	Very loud
Forte	***f***	Loud
Mezzo-forte	***mf***	Moderately loud
Mezzo-piano	***mp***	Moderately quiet
Piano	***p***	Quiet
Pianissimo	***pp***	Very quiet
Pianississimo	***ppp***	Very very quiet
Crescendo	***cresc***	Increasing
Decrescendo	***decresc***	Decreasing
Diminuendo	***dim***	Diminishing

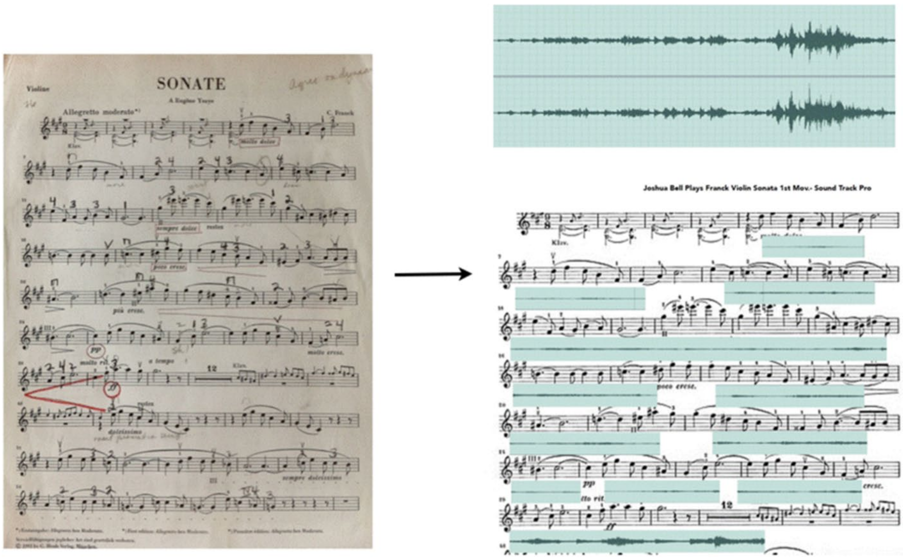
learning process, enhancing their ability to accurately replicate the intended dynamic variations in their performances.

To illustrate, Fig. 1 visualizes the first movement of "Violin Sonata in A Major" by César Franck (1822–1890), using the American violinist, Joshua Bell’s performance. This visualization clearly demonstrates how dynamic changes are reflected in amplitude variations. Our goal is to leverage such dynamic visualizations to allow students to visually observe how their instructors interpret dynamics and compare these visualizations with their performances. This approach aims to enhance the effectiveness of music education by providing a more tangible means of understanding and applying dynamic interpretation.

3.2 Use of the interface

This interface supports students in understanding and applying musical expressions more clearly. The primary use of the MDVM is to maximize the educational efficiency of dynamics by allowing students to intuitively and visually observe their teacher’s dynamics and mimic them in real-time. To achieve this, the MDVM includes features that enhance interaction between teachers and students. Teachers can input their performance, visualize it, and use this visualization as a teaching tool, further reinforcing the learning process by overlaying the student’s visualization onto the teacher’s for more efficient dynamics instruction.

Additionally, the visualizations provided by the MDVM can be utilized in various educational settings. For instance, students can repeatedly practice with their teacher’s visualizations at home and intuitively analyze their dynamic changes through the interface. The MDVM also allows students to compare their current practice sessions with previous ones, providing a clearer understanding of their progress. Furthermore, students can



(a) Franck Violin Sonata 1st Mov. Original Sheet Music

(b) Visualization Made by Joshua Bell’s Recording

Fig. 1 Visualization concept of MDVM share their practice results in real-time with their teachers to receive immediate feedback. Consequently, the MDVM enables more effective communication of dynamic performance between teacher and student, even in remote learning environments, thereby enhancing the achievement of educational goals.

Thus, the use of this interface aids students in gaining a comprehensive understanding of musical expression, particularly the importance of dynamics. Through the MDVM, students can refine their performances with greater precision, ultimately enhancing their overall musical expressiveness. In essence, the MDVM functions as more than just a practice tool; it serves as an educational resource that intuitively teaches students how to effectively express music. This approach not only provides students with opportunities for self-directed learning but also enables teachers to deliver instructional content more efficiently.

4 Musical dynamics visualization method (MDVM)

4.1 Overview

Our proposed method, MDVM, leverages this process by enabling students to visually replicate the dynamic variations demonstrated by their teachers, thereby enhancing their ability to express music more effectively. MDVM aims to enhance interaction between teachers and students, ultimately improving the quality of music through dynamic practice activities.

In the MDVM, (a) once the teacher selects the music score image file of a specific piece, they can input their performance audio (User Input). (b) Then, while playing the music, MDVM can generate and save the dynamic visualization (Visualization). (c) Subsequently, when a student performs, the dynamics of their performance are visualized in a different color, overlaid on the teacher's visualization, allowing the student to observe and compare in real-time (Layered Visualization). (d) This allows the student to compare their performance with the teacher's professional recording and visualization, enabling them to intuitively understand the extent of dynamic variation throughout the piece and benefit from enhanced educational outcomes (Comparison). In this process, both visualizations can also be saved. An overview of the flow is shown in Fig. 2.

4.2 Software design

4.2.1 User interface

The view of the player's sheet music was designed to use an image file of the original music score and an overlaid translucent sketch of the waveform (Fig. 3).

The design uses the original style score to maintain the natural environment of classical musicians, but combined with the modern graphical display of the waveform image. The waveform is based on calculations of the average signal volume over the time frame of a frame redraw. In this way, we wanted to create a connection between sound, sight, and touch (Fig. 4).

It allows new score image files to be imported with audio files and calibrated so that the waveform correctly aligns with the score. To take advantage of the ability to interact with the interface by touch, keeping in mind that users' hands are usually busy with their instrument during practice, a feature was implemented where the user listens to the recording

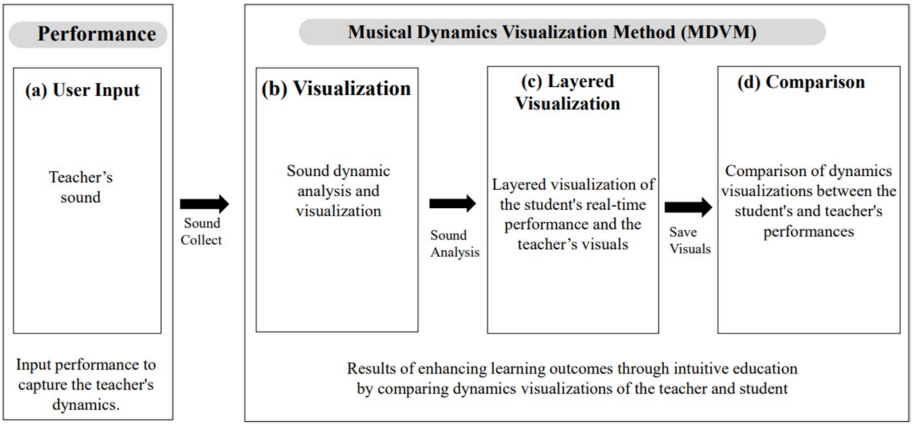


Fig. 2 Teacher-student interaction

Fig. 3 Tablet as a new sheet music

and touches the corresponding bar line as it is heard in sequential order. These data are saved so that the bar line timing and visualization drawing position are consistent for future listens and recordings.

4.2.2 Visualization feature

In the main menu of the MDVM, users can select the song they wish to play. Upon selection, the corresponding sheet music appears, allowing users to visualize their performance. The actual visualization is created by checking the signal volume of the sound at 0.03-s intervals, calculating it, and then generating a waveform-based graph in real-time (Fig. 4).

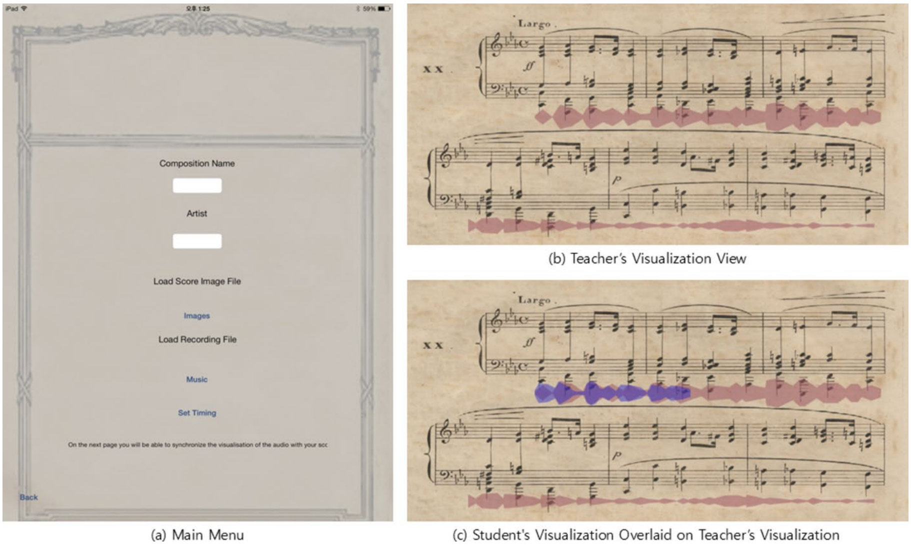


Fig. 4 Visualization frame

Visualization involves several key features to ensure accuracy and clarity. First, the sound volume is measured to ensure consistency, and the plane is chosen over a line for better comparison. Second, to facilitate a more effective comparison, the visualization images are rendered as translucent. Third, the ratio of the visualization is adjusted to position it between the systems in the sheet music. Fourth, the visualization curve is smoothed relative to the original signal to allow for more intuitive viewing. Fifth, the visualization is implemented so that the teacher's and student's visualizations can be overlaid for comparison. Sixth, to clearly distinguish between the two visualization images, they are represented in two different colors (Fig. 4).

5 Experiment

The objective of our experiments was to investigate the role of MDVM in teaching musical dynamics and assess the effectiveness of this method compared to traditional teaching approaches. We aimed to determine how effective this interface was in educating students relative to conventional methods. To show the effectiveness of our proposed MDVM, we first performed the pre-test experiment (Section 5.1.1). Moreover, we demonstrated the effectiveness of our model through the main-text experiment (Section 5.1.2), which was based on significant results from the pre-test.

5.1 H/W and S/W

To facilitate interaction between musicians, teachers, and students through the MDVM, we established the development environment as outlined in Table 2. This setup is specifically designed to support the effective implementation and functionality of the MDVM (Table 2).

Table 2 MDVM development and testing specifications

Component	Specification
Platform	Objective-C for iOS and macOS devices
Testing environment	Apple iPad2 with dimensions: 9.5 inches (height), 7.31 inches (width), 0.34 inches (depth), and weight: 1.33 pounds (601 g) [Wi-Fi model]
Display characteristics	9.7-inch multi-touch display, resolution of 1024 * 768 pixels at 132 ppi
Audio capabilities	Microphone and stereo audio output via a 3.5 mm headphone jack
Development tools	iPad SDK for player's sheet music display, supporting Objective-C via the X-Code development environment
Graphics framework	OpenGL ES for rendering high frame rate waveform visualizations
Analysis tool	Statistical Package for the Social Sciences (SPSS)

5.2 Data

In our study, three conditions were conducted to evaluate the effectiveness of MDVM rigorously. Condition (1) is performance without exposure to the MDVM. Condition (2) is performance after observing the teacher's dynamic visualization through the MDVM. Condition (3) is performance comparing the student's visualization layered in real-time over the teacher's visualization through the MDVM.

In our experiment, a single music piece featuring eight distinct dynamic changes was selected for evaluation. At each section where dynamic changes occurred, teachers measured the errors in students' dynamic expressions. The data captured the progression of students' dynamic interpretation across the three conditions.

5.3 Experiment method

Participants were instructed to use the MDVM to calibrate the waveform playback timing for a piece of music, compare their waveform with the recordings while playing the piece, and create a recording. For evaluation purposes, "Long Long Ago" by Thomas Haynes Bayly (1797–1839), included in Suzuki Violin Book 2, was selected due to its eight distinct dynamic changes, and it was used for both performance and assessment. Teachers completed evaluations of the students' musical performance using modified versions of the Performance Scale (WFPS) and the Farnum String Scale (FSS), which are established metrics for assessing musical performance [14]. The changes in students' dynamic interpretation across the three conditions were assessed.

The pre-test participants were two students and three teachers; students who were 17 and 19 years old and were studying for over 7 years and two violin teachers and one viola teacher participated. Before testing all the participants, we conducted a pre-test. Specifically, 52 students participated in the main test for more sophisticated experiments. They were recruited using convenience sampling, and all participants reported having prior experience as musicians. The ratio of male to female participants was 3:7, with ages ranging from 16 to 20 years. Participants were asked to test the application by calibrating the waveform playback timing for a piece of music, comparing their own waveform with the recordings while playing the piece, and creating a recording.

5.4 Experiment results

5.4.1 Pre-test: Comparison of improvement by conditions (Two students)

The pre-test participants were two students and three teachers (two violin teachers and one viola teacher). The students were 17 and 19 years old and had been studying for over seven years. The two tested students had similar results.

In Condition (1), performance without exposure to the MDVM, both exhibited 100% errors in musical dynamics. However, in Condition (2), performance after observing the teacher's dynamic visualization through the MDVM, they showed a reduction in errors to 75% and 62.5%, respectively. In the final Condition (3), performance comparing the student's visualization layered in real-time over the teacher's visualization through the MDVM, their errors decreased to 0%. These clear results indicate that dynamic visualization plays an effective role in music education. Simply showing the teacher's dynamic visualization helped students perform more accurately. Consequently, we decided to continue this method of experimentation and evaluation with other students. Additionally, three teachers evaluated the musical expression in the students' recordings. All three teachers agreed that the recordings made after the students had been trained with dynamic visualization were considerably more expressive; 100% of the teachers selected the recordings made following the dynamic visualization as demonstrating better musical expression (Fig. 5).

5.4.2 Main test: Comparison of improvement by conditions (52 students)

This section presents the evaluation process and results. The outcomes demonstrate the improvement of students, as measured by objective assessments conducted by music teachers using the MDVM. The results are as follows.

As the evaluation focused on errors in the direction of dynamic changes at eight specific locations within each measure, the error average (EA) in the table below represents the mean error across these eight sections. "N" (samples) refers to the number of performer samples used in the experiment.

Table 3 presents the numerical results. Error average (EA) is defined as the average error across the eight dynamic change sections, whereas N (samples) is defined as the number of samples used in our experiment. According to the results in Table 3, EA was recorded as 2.19 in Condition 3, showing a 178% to 256% improvement compared to the other conditions. This experiment demonstrates the remarkable effectiveness of our MDVS (Table 3).

In Condition (1), performance without exposure to the MDVM resulted in an EA of 7.85. In Condition (2), performance after observing the teacher's dynamic visualization

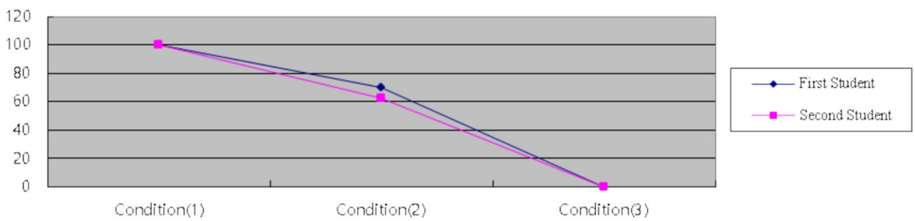


Fig. 5 Result of the pre-test

Table 3 Comparison of measurement results for the three conditions

Condition	Error Average (EA)	Specification
Condition (1)	7.85	52
Condition (2)	6.1	52
[a] Condition (3)	2.19	52

[a]Best score

through the MDVM, the EA was reduced to 6.1. The most substantial improvement was observed in Condition (3), where performance with the student's visualization layered in real-time over the teacher's visualization through the MDVM led to a much lower EA of 2.19.

The results indicate that students in Condition (2) made fewer errors than those in Condition (1), demonstrating the benefit of visualizing the teacher's musical dynamics. However, the most substantial reduction in errors occurred in Condition (3), where the ability to see both the teacher's and their own visualizations in real-time led to a dramatic improvement in expressiveness.

5.4.3 Main test: One-way ANOVA: Comparison of three conditions

We demonstrate the superiority of our method based on the data analysis in Table 4. The error difference between Condition (1), performance without exposure to the MDVM, and Condition (2), performance after observing the teacher's dynamic visualization through the MDVM, was 1.75. The error difference between Condition (2) and Condition (3), performance comparing the student's visualization layered in real-time over the teacher's visualization, was 3.9. Therefore, students ' performances in Condition (2), after observing the teacher's dynamic visualization, were better than those in Condition (1), without MDVM exposure. Additionally, the performances in Condition (3), with real-time layering of student and teacher visualizations, were significantly outperformed those in Condition (1) and Condition (2) (Table 4).

Figure 6 illustrates that the performance in Condition (2), where students observed the teacher's dynamic visualization through the MDVM, resulted in fewer errors compared to Condition (1), where students performed without exposure to the MDVM. Furthermore, the performance in Condition (3), where the student's visualization was layered in real-time over the teacher's visualization through the MDVM, demonstrated significantly fewer

Table 4 One-way ANOVA: Comparison of three conditions

(I) Comparison factor	(J) Comparison factor	EA difference (I–J)	Std. error	Significance level
Condition (1)	Condition (2)	1.75000	0.19635	0.000
	Condition (3)	5.65385	0.19635	0.000
Condition (2)	Condition (1)	−1.75000	0.19635	0.000
	Condition (3)	3.90385	0.19635	0.000
*Condition (3)	Condition (1)	−5.65385	0.19635	0.000
	Condition (2)	−3.90385	0.19635	0.000

[a]Mean difference is significant at the 0.05 level. / [b] Condition is abbreviated as "C"

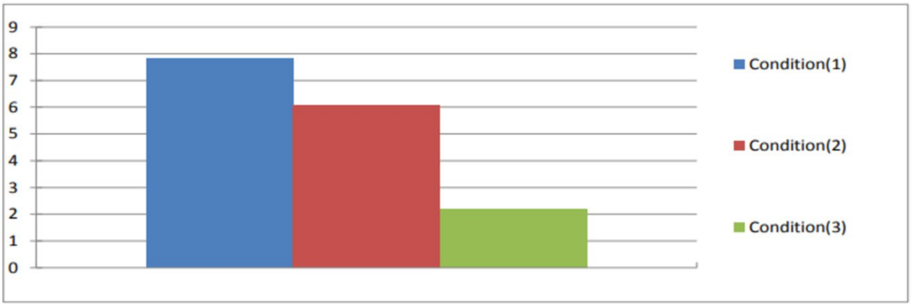


Fig. 6 Result of Conditions (1), (2), and (3)

errors compared to both Conditions (1) and (2). This finding substantiates the educational effectiveness of the MDVM (Fig. 6).

As a result of using the MDVM, the number of errors made by students during performance decreased significantly. Additionally, after observing the teacher's dynamic visualization through the MDVM, further reductions in some errors were observed. These findings demonstrate that this interface effectively supports the students' education in musical dynamics.

5.4.4 Comparison analysis with other methods

This section presents a comparison between our study and similar research. The most closely related work, MEAWS [13], proposed a comparable educational method for visualizing musical dynamics, sharing a similar structure with our approach. Additionally, DYNAGRAMS [9] visualizes musical dynamics by comparing dynamic changes between professional and non-professional performers. Similarly, DYNAMICS MODELING [11] focuses on music performance analysis and modeling, developing models to describe and recreate the dynamic properties of expressive performances. Furthermore, VISUALIZATION OF MUSICAL PITCH [6] centers on music education and practice, offering a performance analysis system that visualizes. Specifically, our study sets itself apart from previous research by rigorously demonstrating the concrete effectiveness of the dynamic visualization approach through experimental validation.

Table 4 highlights the differences between our study and existing research. It is important to note that comparisons are challenging due to the variability in experimental conditions, which complicates achieving a fully equitable comparison. Nevertheless, the comparison in Table 5 provides valuable insights into the trends and outcomes of these experiments.

6 Summary

This study evaluated the effectiveness of the MDVM by analyzing the error rates in musical dynamics interpretation across three different conditions. The EA was calculated for each condition, based on the eight distinct dynamic change sections.

Students who utilized the MDVM showed a marked reduction in performance errors, especially when the students played with the visualization layered in real-time over the teacher's

Table 5 Comparative analysis with other methods

Method	Purpose	Description	Methodology	Effect and Result
MEAWS [13]	Music education and practice	Performance analysis system providing visualization of musical elements	Simple visualization of dynamic detection shape in a specific section	Provides an objective tool for evaluating students' practice accuracy, improving their performance, and easily monitoring progress or comparing with peers
DYNAGRAMS [9]	Music visualization	Recording program called —— DYNAGRAMS	Simple visualization comparing dynamic changes between professional and non-professional performers	Demonstrates the superiority of expert pianists over non-experts through visual comparison of dynamic performance
DYNAMICS MODELING [11]	Music performance analysis and modeling	Models developed to describe and recreate dynamics properties of expressive performances	Multi-layered approach to dynamics, allowing flexibility in defining various dynamic shapes	Demonstrates the positive impact of flexibility (freedom) through comparative analysis of human stylistic homogeneity, past known performance, recurring sections, and specific sections in dynamic aspects
VISUALIZATION OF MUSICAL PITCH [6]	Music education and practice	Performance analysis system providing visualization of musical pitch	Visualization of pitch detection in specific sections and on the musical score	Provides a visualization for pitch detection and 1/20th of a second detection performance through experiments
MDVM (Our method)	Music education and practice	Music Dynamics Visualization Method	Comparison of educational effects through real-time dynamic performance changes between professionals and non-professionals	Enhances educational efficiency in dynamic musical expression, reducing dynamic error rates by approximately 256%

[a] Measurement indicator: musical dynamics

visualization. This finding underscores the system's utility in helping students not only grasp the concept of musical dynamics but also apply it more precisely in real-time performance contexts.

Overall, these findings highlight the remarkable effectiveness of the MDVM in enhancing students' interpretation and performance of musical dynamics, with Condition (3) showing a 178% to 256% improvement compared to the other conditions.

7 Limitation and future work

The primary limitation of this study is its exclusive focus on musical dynamics. While dynamics are indeed a crucial element in music education, other important aspects of musical expression, such as pitch and rhythm, also play a critical role. Developing an interface that integrates all of these elements could potentially maximize the efficiency of music education.

Moreover, the relative nature of dynamics presents technical challenges in accurately visualizing amplitude changes. The interface is designed to highlight general dynamic changes rather than precisely reproduce them, which limits its ability to visualize dynamics with the exactitude needed to fully replicate musical expression.

To address these limitations, future research should aim to expand the capabilities of the interface. For instance, developing a visualization tool that integrates dynamics with pitch and rhythm recognition could substantially enhance musicians' ability to manage various aspects of their performance comprehensively. Furthermore, exploring more sophisticated technical methods for translating auditory elements into visual representations could provide even more interactive and expressive experiences in educational and practice settings, fostering better interaction between teachers and students.

In summary, although this study successfully visualized dynamics and validated its effectiveness, we acknowledge the need to broaden the scope to include other elements of musical expression. Future research should focus on developing tools that support both the precision and creativity required in music education, ultimately offering greater assistance to musicians in their artistic development.

Additionally, follow-up studies could further validate the interface's effectiveness by incorporating evaluations focusing on subjective assessments and user satisfaction. Such additional evaluations could underscore the importance of MDVM as a comprehensive tool that supports not only technical precision but also artistic development and user satisfaction.

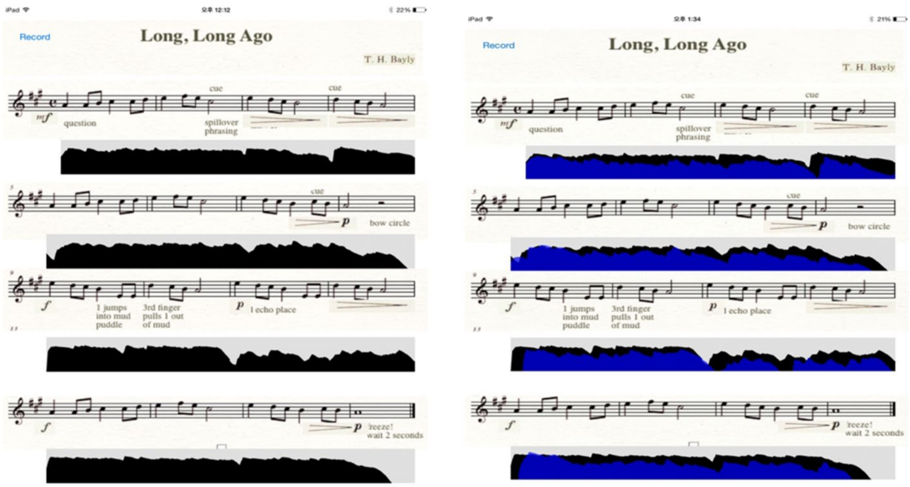
MDVM plays a crucial role in enhancing students' learning outcomes by providing a visual representation of musical dynamics in music education. Future research could expand its capabilities by incorporating additional elements such as pitch and rhythm to offer a more comprehensive educational experience. Furthermore, by integrating elements such as pitch and rhythm, the interface could facilitate more effective teacher-student interaction in music education.

8 Conclusion

In conclusion, the MDVM was demonstrated to be a powerful tool for effectively enhancing dynamic expression in music education. By converting sound into permanent images, the system enables continuous comparison and improvement, offering a more effective approach to musical practice than traditional methods that rely on pencil-and-paper notation and auditory memory. Its capabilities in real-time visualization, comparison, and data storage allow students to deepen their understanding of musical expression while effectively balancing technical precision and artistic interpretation. As a result, the MDVM has the potential to complement traditional teaching methods and introduce a new paradigm in music education.

Furthermore, the MDVM is poised to represent an innovative approach to teaching dynamic expression through visualization, positioning itself as a tool with the potential to considerably affect music instruction. The implications of this study could extend to improving contemporary pedagogical approaches and potentially transforming the future paradigm of dynamic music education.

Appendix



(a) The score view of the teacher's waveform

(b) The Score view of the student's waveform

Fig. 7 Score view

Author contributions Not applicable as this is a single-author study.

Funding Open Access funding enabled and organized by Seoul National University.

Data availability The data from this study is available for sharing.

Declarations

Competing interests The authors have no competing interests to declare relevant to the content of this article.

References

1. Kamenetsky SB, Hill DS, Trehub SE (1997) Effect of tempo and dynamics on the perception of emotion in music. Psychol Music 25(2):149–160. https://doi.org/10.1177/0305735697252005
2. Chapin H, Large E, Jantzen K, Kelso JAS, Steinberg F (2008) Dynamics of emotional communication in performed music. J Acoust Soc Am 124(4_Supplement):2432–2432. https://doi.org/10.1121/1.4782507
3. Read G (1979) Music notation: A manual of modern practice. Taplinger Pub. Co., New York
4. Thiemel M (2001) Dynamics. Grove Music Online. https://www-oxfordmusiconline-comssl.libproxy.snu.ac.kr/grovemusic/view/10.1093/gmo/9781561592630.001.0001/omo-9781561592630-e-0000008458. Accessed 21 Jan 2025
5. Lindström E, Juslin PN, Bresin R, Williamon A (2003) 'Expressivity comes from within your soul': A questionnaire study of music students' perspectives on expressivity. Res Stud Music Educ 20(1):23–47. https://doi.org/10.1177/1321103X030200010201
6. McLeod P, Wyvill G (2003) Visualization of musical pitch. Proc IEEE 2003:300–303. https://doi.org/10.1109/CGI.2003.1214486
7. Alexander J (2010) Visualising key & Tempo in music. CiteSeerX. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=6bb5858685dd28b5a231b0bfa6b3cbe92bd4eb15. Accessed 21 Jan 2025
8. Lima HB, Dos Santos CGR, Meiguins BS (2022) A survey of music visualization techniques. ACM Comput Surv 54(7):1–29. https://doi.org/10.1145/3461835
9. Langner J, Kopiez R, Stoffel C, Wilz M (2000) Realtime analysis of dynamic shaping. In Proceedings of the 6th international conference on music perception and cognition. Keele, UK. Keele University, Department of Psychology, pp 452–455
10. Krumhansl CL (2002) Music: A link between cognition and emotion. Curr Dir Psychol Sci 11(2):45–50. https://doi.org/10.1111/1467-8721.00165
11. Berndt A, Hähnel T (2010) Modelling musical dynamics. In Proceedings of the fifth audio mostly conference, (1–8). Location. https://doi.org/10.1145/1859799.1859817
12. Percival GK (2008) Computer –assisted musical instrument tutoring with targeted exercises. Master's thesis. University of Victoria
13. Percival GK, Wang Y, Tzanetakis G (2007) Effective use of multimedia for computer-assisted musical instrument tutoring. In Proceedings of the international workshop on educational multimedia and multimedia education, pp 67–76. https://doi.org/10.1145/1290144.1290156. ACM, Location
14. Boyle JD, Radocy RE (1987) Measurement and evaluation of musical experience. Schirmer Books, New York