Thunder: A Design Process to Build Emotionally Engaging Music Visualizations

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ABSTRACT

Music's profound emotional impact extends beyond traditional listening experiences, playing a critical role in shaping user engagement in entertainment contexts, including digital games. Music visualizations – graphical representations of musical elements such as rhythm, melody, and harmony – are becoming increasingly significant for enriching emotional depth in these contexts. Despite the potential of music to enhance digital media experiences, there remains a gap in the intentional integration of musical visualizations with specific emotional narratives. In this paper, we propose Thunder, a design process for creating musical visualizations that prioritize conveying the emotional communication of music. Our approach builds on an existing method for rapid prototyping of animated musical visualizations and comprises four iterative phases. By applying this process in creating two music visualizations, we demonstrate that our process aligns closely with the designed emotional content of the music. The results showed that our alternative visualizations effectively communicated intended negative emotions, such as "sadness" and "shame", and were well-received by the public, highlighting the importance of synchronized visual and musical elements. With this work, we hope to offer valuable insights for game designers and entertainment app developers, providing a comprehensive design process for crafting musical visualization experiences that emphasize the emotional richness of music and pave the way for more immersive and emotionally resonant digital media experiences.

CCS CONCEPTS

• **Human-centered computing** → **Visualization design and evaluation methods**; *Accessibility technologies*; **Interaction design process and methods**.

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1 INTRODUCTION

Music is a powerful way of expression in human culture. It goes beyond the limits of cultures, geographies, and societies [35, 38], evokes emotions, and conveys complex moods [29, 39]. The literature has shown how the influence of music on our emotions brings up its uses in several fields. For example, music has been found helpful as an intervention in enhancing emotional well-being and associated with benefits for people with clinical depression and anxiety [17, 25]. Because it can serve as a mechanism for regulating mood [27, 42], and is also associated with the release of dopamine and oxytocin, which are linked to pleasure and social bonding[8].

With its strong emotional appeal, music naturally applies to interactive applications, especially within the entertainment domains [36, 48], which include video games, virtual environments, interactive art, and storytelling, to name a few. Much more than simple background sound, music can deeply impact user experience (UX) by deepening immersion [12, 18], affective engagement [18, 22], and the feelings of aesthetic experience [12]. It has also been associated with a stronger behavioral intention and a more positive perception towards a target interactive application [22].

In this context, music visualization has gained much attention as a field for applications in entertainment, education, art, and commerce, which can incorporate music, digital audio, image processing, and virtual reality [49]. Music visualizations are graphical representations of musical elements such as rhythm, melody, and harmony [10, 31, 39]. They may appear in very diverse forms, such as dynamic animations [30], color patterns [13], and forms reacting to the music [4]. Besides enhancing the aesthetic appeal of digital applications, music visualizations apply in practice in various digital contexts. One example is they are similarly helpful in improving accessibility and understanding, especially for people with hearing or cognitive disabilities. [16, 39].

While it's well established that music can deepen emotional experiences in interactive applications, the effective integration of musical visualizations into specific narratives in digital media remains challenging. An inherent difficulty is balancing the auditory and visual stimuli to produce a coherent and effective experience. Users often find difficulty in interpreting the association's relevance between graphically represented sounds and the overall narrative Siu et al.. This task is further complicated by the intrinsic nature of the perception of emotions in music being subjective. Creating effective musical visualizations requires a deep understanding of how this media triggers emotions and conveys complex information in parallel. To avoid diverting from the intended emotional impact, the designer must be meticulous about how sounds and graphics might work together to arouse emotions deeply tied to the music and augment the digital narrative. That raises our research question: How can we develop a systematic approach for designing musical visualizations that effectively communicate a piece of music-related emotions within digital narratives?

In this context, our paper introduces a design process for creating musical visualizations that prioritize conveying the emotional essence of music. We called it Thunder[1]. This approach builds upon the method proposed by Almeida et al. (2021) for rapid prototyping of animated musical visualizations. Our iterative process comprises four phases: (1) Conceptualization, (2) Prototyping, (3) Implementation, and (4) Evaluation. Each phase involves understanding and evaluating the visualization's musical, aesthetic, and emotional aspects, considering the source song and how these elements influence the user's interpretation and perception of the emotional communication.

We then applied Thunder to develop two music visualizations for the song "The Sixth Station", composed by Joe Hisaishi. Results show evidence suggesting the resultant visualizations conform to the emotional content of the music. While our process provides a good foundation for designing musical visualizations with strong emotional depth, it doesn't yet deal with user interaction with the visualization, which will be a focus in future work.

This work presents a structured approach for designing musical visualizations that are more than just visual accompaniment. We aim to help creators communicate music's emotional content to people by incorporating its emotional subtleties into the design process of musical visualizations. We expect Thunder to help create more effective and engaging musical visualizations in the rapidly changing world of interactive media, virtual environments, games, digital art, multimedia installations, and entertainment applications.

2 BACKGROUND

In this section, we present a background on the influence of music on human emotions and discuss the process involved in creating a visualization that represents the essence of music through selected components.

[1]Thunder is a strong metaphor for the forces unseen. It symbolizes something invisible behind a storm, similar to how our process uncovers the unseen emotions behind the music, making them visible and palpable through captivating visuals.

2.1 Music and Emotions

The relationship between music and emotions has fascinated researchers across various disciplines, including musicology, psychology, and neuroscience. Music is important in evoking emotions, creating a pleasant atmosphere, expressing inner feelings, and enhancing creative behaviors [41]. Music can also be used to encode emotional information; for instance, a movie soundtrack can set the mood of a scene and affect the emotional perception of the audience[32]. Take, for instance, the iconic, minimalist theme from "Jaws," a simple alternation of E and F notes. As Matessino points out (1999), many North American adults instantly associate it with a lurking shark and impending doom, even outside the context of the film.

Expanding on this understanding, Cowen et al. (2020) investigated the subjective experiences associated with Western and Chinese music, examining whether these experiences transcend cultural boundaries. Their findings revealed 13 distinct dimensions of subjective experience linked to music across both cultures: "amusing," "annoying," "anxious/tense," "beautiful," "calm/relaxing/serene," "dreamy," "energizing/pump-up," "erotic/desirous," "indignant/defiant," "joyful/cheerful," "sad/depressing," "scary/fearful," and "triumphant/heroic." This comprehensive mapping underscores the diverse emotional palette music can elicit.

The emotional power of music derives from a very complex interaction of auditory stimuli and cognitive processing. Contributory factors in such expressiveness lie in the structural elements of music: tempo, melody, harmony, and dynamics. These elements combine and interact with listeners' cognitive and affective systems to elicit responses, which may be individual or shared. Manipulating these musical elements can raise targeted emotional responses.

Psychology and neuroscience research prove that music provokes physiological and neural responses, laying concrete proof of its impact on our bodies. Koelsch (2014) highlights functional neuroimaging studies demonstrating music's ability to modulate activity in brain regions intrinsically linked to emotions, such as the amygdala and hypothalamus. It translates into physiological and autonomic and endocrine changes; motor expressions are expressed through a smile or a frown, and action tendencies mean tapping your feet or hitting the dance floor. Music can stir real emotions beyond mere subjective feelings because it can affect the roots of emotional responses.

2.2 Music Visualization

Visualizations encompass a range of techniques and methods for creating graphics, images, and animations to communicate information effectively [51]. Music visualizations, a subset of this field, merge music and visual elements to produce synchronized and immersive experiences that enhance the viewer's engagement with the music [46]. Moreover, music visualizations offer an accessible way to experience music, particularly for the deaf, deafened, and hard of hearing (D/HH) communities, who seek to access music from mainstream hearing culture [39]. Music poses significant challenges for individuals who are D/HH, as they often encounter obstacles when attempting to engage with music designed for hearing audiences [16]. Furthermore, partial and total hearing loss can hinder the

ability to comprehend and enjoy music, even with hearing aids, which may distort the quality of the music [9].

Music visualizations have come a long way, especially in artistic areas, such as operas, ballets, and movies [19]. For instance, the film "Fantasia" [1] developed by Disney in 1940 was produced using artistic interpretations of selected musical works. Through various degrees of abstract and literal art in the form of visual animation, "Fantasia" effectively communicates emotion, entertainment, and other music properties [16]. Another early use of electronics to visualize music through art occurred with the release of the Atari Video Music system [2] in 1978. Designed to connect to a television set, this console allowed users to either create their own visual effects or place the system in automatic mode where the visuals responded dynamically to the music [6]. These displays were precursors to modern software-based music player visualizations [16]. Furthermore, with the advance of technologies, music players such as Windows Media Player and iTunes started to use software algorithms to automatically extract key music data, such as frequency and time, from digital music files, translating this data into visualizations.

3 CONSTRUCTING A DESIGN PROCESS

This section presents our approach to propose and refine the proposed design process – Thunder (see Figure 1) –, which included an initial evaluation of pre-existing musical visualizations, the selection of techniques, and how each step relates to the original process proposed by Almeida et al. (2021).

3.1 Initial Evaluation

Before establishing the process, we evaluated five musical visualizations presented during a live thematic concert featuring Studio Ghibli by the Federal University of Ceará (UFC) String Camerata at the Museum of Image and Sound Chico Albuquerque. The visualizations were developed outside the scope of this research, using a conventional multimedia design process within a computational design research project led by fellow researchers from the Computational Design Group of the UFC Digital Experience Laboratory (LED). They showcased musical visualizations themed around Studio Ghibli films, presenting the songs: *Itsumo Nando Demo* from "Spirited Away"; *Country Road* from "Whisper of the Heart"; *Sanpo* from "My Neighbor Totoro"; *Mononoke Hime* from "Princess Mononoke"; and *The Sixth Station* from "Spirited Away." These visualizations featured graphical elements that dynamically responded to characteristics of the music being performed by the Camerata, such as pitch and intensity, providing a visually engaging accompaniment to the live performance without explicitly aiming to convey the emotions of the music.

The evaluation comprised two parts: word associations and user evaluations during a live String Camerata presentation. For the word associations, two evaluators listened to the Studio Ghibli music twice and noted down words referring to emotions, places, or elements associated with each piece on a spreadsheet. In the user evaluations, 57 audience members provided opinions on the Studio Ghibli visualizations presented alongside the music. The PrEmo Measurement Tool [14] was used to understand the emotions evoked by each visualization, with participants indicating their feelings based on graphical representations. During intermissions, application time was about one and a half minutes. After the presentation, the IMI-TEQ-Br Interest/Enjoyment dimension [37] measured participants' motivation and interest, and the UES-Br Short-Form questionnaire [34] assessed audience satisfaction with the visualizations. Both questionnaires were administered using Google Forms immediately after the performance. The results of this evaluation are described in Section 5.1.

Based on the initial evaluation results, we selected a visualization to apply our process, developing two alternative music visualizations.

3.2 Implementation of the Process

Based on the work of Almeida et al. (2021), we established the steps of the process, considering emotional communication aspects and techniques for conceptualization and evaluation. Initially, we planned a comprehensive validation stage but later modified the process by dividing this stage into Evaluation and Implementation, incorporating additional techniques to enhance the process.

After defining each phase, we applied them to developing a musical visualization through an iterative process. Two designers independently followed this process, generating continuously evaluated and refined prototypes. This iterative approach involved revisiting and adjusting the process at various stages to ensure optimal outcomes. In the following sections, we present each phase, discussing its relation to the work of Almeida et al. (2021) and the techniques we selected. In Section 4, we present the results of the iterative application of this process.

3.2.1 Conceptualization. The Conceptualization phase is in line with the Inspiration and Synthesis phases described by Almeida et al. (2021), during which decisions are made about what aspects of the music would be represented and what messages would be communicated. This comprises the decision of the music and which aspects of the visualization will interact with the music. In addition to the musical aspects, we added a stage for defining the emotional communication that the music conveys and conceptualizing the aesthetic aspects explored in the visualization.

We chose two techniques to understand the perceived emotional communication: (1) emotional mapping and (2) word associations. These methods were selected because they complement each other in capturing both quantitative and qualitative aspects of emotional responses to music. Emotional mapping was chosen for its structured, data-driven approach, essential for identifying emotional similarities and differences across musical pieces. The interactive map from Cowen et al. (2020) [2] provides a comprehensive visualization of subjective experiences evoked by music. It uses a 13-dimensional categorical space to plot 1,841 music samples along two axes based on their highest-loading judgment dimension. This allows the designer to observe similarities between songs and understand the dimensions of evoked emotions. Such detailed, quantitative analysis is crucial for ensuring that the emotional nuances of the music are accurately represented in the visualizations.

We chose word associations to complement emotional mapping because they offer qualitative insights into the specific emotions

[2]https://www.ocf.berkeley.edu/ acowen/music.html

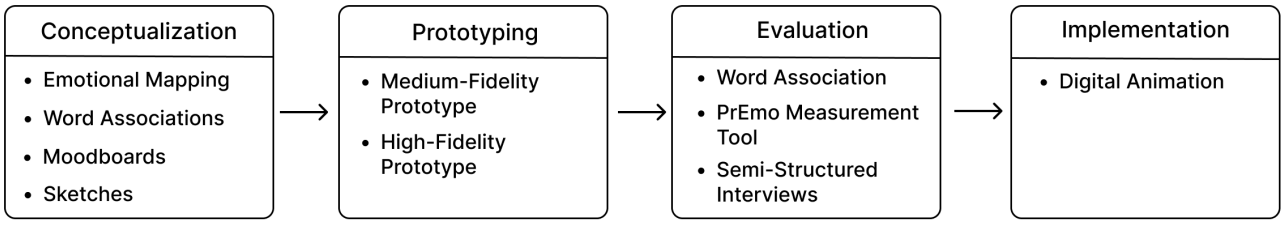

Figure 1: A resume of the proposed design process - Thunder.

and themes that resonate with listeners. Conducting word association exercises enables designers to identify keywords that evoke the emotions induced by the music, pinpointing the primary emotional themes and musical elements that will guide the visual design. This technique ensures that the visualization captures the aesthetic essence of the music and effectively communicates its emotional impact. By combining these qualitative insights with the quantitative data from emotional mapping, we can create visualizations that are both accurate and emotionally resonant. Together, these techniques provide a comprehensive understanding of emotional communication in music, ensuring that the visualizations not only reflect the music's emotional content but also engage viewers on a deeper emotional level. Based on this initial exploration, the designer can select the main words to guide emotional communication and the key musical elements that influence the visual interactive elements.

In the phase of conceptualizing the aesthetic aspects, we chose two techniques: (1) moodboards and (2) sketches. These methods were selected for their effectiveness in visually organizing and refining abstract concepts into a cohesive aesthetic direction. Moodboards were chosen because they allow designers to consolidate their ideas and inspirations during the rapid prototyping stage. They provide a visual way to organize abstract concepts and help establish a unified aesthetic direction. We chose sketches to complement moodboards as they enable the translation of visual references into concrete designs. After developing the moodboards, the designer should create an initial sketch of the visualization, connecting the visual references with the associated words. This initial sketch serves as a blueprint for integrating interactive visual elements representing musical components, such as frequency, timbre, and beat. Following this step, we established the first feedback session to gather input on the defined concepts and the initial sketch. This iterative process allows for refinement and ensures that the final visualization effectively communicates the desired emotional and aesthetic qualities. By combining mood boards and sketches, we can systematically develop and refine the visual aspects of the project, ensuring a coherent and emotionally resonant design.

One challenge faced during this phase was that the designers encountered difficulties due to their lack of specialized knowledge in music, which required additional study to choose suitable musical components that would be represented by the visual elements.

3.2.2 Prototyping. The Prototyping stage is related to the Ideation stage in [5], in which prototypes are developed to test the ideas. For this step, we opted for developing a medium and high-fidelity prototypes and feedback sessions between each iteration.

3.2.3 Medium-Fidelity Prototype. At this stage, the designer must develop a medium-fidelity prototype based on the initial refined sketch. We have established that, for medium fidelity, the prototype should consist of a few frames drawn with the music playing in the background, with the selected color palette applied, giving an idea of the positioning of elements on the screen and simplified examples of visual interactions.

After creating this prototype, a feedback session must take place to collect feedback regarding the emotional communication and aesthetic decisions. This approach allows the identification of potential design issues that could affect the visualization's emotional communication and refinement of its aesthetic aspects based on our objectives. After refinement, the High-Fidelity Prototype should be produced.

3.2.4 High-Fidelity Prototype. For this prototype, we established that it should consist of an animation, simulating the programmed musical visualization as faithfully as possible to what the final product should look like so that it can be evaluated by users from the target audience. After finishing the prototype, another feedback session must take place to address potential improvements in emotional communication and aesthetic aspects and to identify and correct any design problems to ensure that the final visualization can effectively communicate the intended emotions.

During this phase, we encountered some challenges, such as the technical limitations of free animation software, which restricted creative possibilities and required us to adapt our ideas to what the software allowed, often necessitating compromises. Furthermore, balancing the iterative process with the project timeline was difficult. It was essential to ensure each iteration genuinely contributed to the design's improvement without compromising established deadlines.

3.2.5 Evaluation - Laboratory Test. The Evaluation phase is related to the Almeida et al. (2021) Validation stage, in which an analysis of the digital prototype is carried out to ensure alignment with the initial objectives. In this step, users from the target audience should validate the High-Fidelity Prototype in a laboratory test. We defined the following objectives for this evaluation: (i) understanding the impact of these visualizations on the public's experience and emotional perception, and (ii) identifying possible modifications to improve them.

We selected three techniques for prototype evaluation: word association, the Product Emotion (PrEmo) measurement tool, and

semi-structured interviews, to provide a comprehensive understanding of emotional responses. The PrEmo measurement tool, a non-verbal scale, uses 14 illustrations to represent emotions—seven positive (joy, hope, pride, admiration, satisfaction, fascination, attraction) and seven negative (sadness, fear, shame, contempt, dissatisfaction, boredom, disgust). This tool provides a structured assessment of the emotional spectrum elicited by the prototype. Semi-structured interviews offer in-depth qualitative feedback, exploring users' emotional experiences in detail and uncovering the reasons behind their responses. For planning this evaluation, we recommend using the DECIDE framework [40] to ensure a structured and comprehensive approach. Combining these techniques allows us to gain a deep and multifaceted understanding of the prototype's emotional impact.

During this phase, we faced some challenges. Due to time constraints, recruiting participants was difficult, resulting in a group without female participation. This limitation affected the diversity of perspectives and insights gathered during the evaluation. Additionally, the subjectivity of emotions posed a challenge in interpreting some data, as it required greater contextualization to understand its meaning. For example, word clouds demanded a more careful analysis to avoid ambiguity.

After the Laboratory Test, a feedback session must occur, during which the evaluation results should be discussed. Based on these results, the necessary refinements in the High-Fidelity Prototype should be made.

3.2.6 Implementation. The Implementation stage is also related to the Almeida et al. (2021) Validation stage, in which the final prototype is transformed into a digital animation by a specialist. After implementation, the final visualization should undergo a field test with the target audience for evaluation.

During this phase, we faced challenges due to time constraints imposed by the project schedule, which made it difficult to complete the implementation stage. As a result, this stage will be finalized and analyzed in greater depth in future studies.

3.2.7 Ethical Considerations in Participant Evaluation. In conducting our evaluation with human participants at the Initial Evaluation and Laboratory Test stages, we adhered to rigorous ethical standards to ensure the safety and anonymity of all involved. Recognizing the sensitivity of collecting data related to emotional responses, we prioritized transparency and informed consent throughout the process. All participants were briefed on the study's purpose, the nature of their involvement, and their rights, including the option to withdraw at any stage without any repercussions. To protect participant privacy, we anonymized all data collected, ensuring that no identifying information was linked to individual responses. Furthermore, we applied the Term of Free and Informed Consent (TCLE), which participants signed before taking part in the study. This document outlined the nature of the study, potential risks, and benefits, and the measures we would take to protect their data.

Although the project has not yet been submitted to an official ethics committee for approval, we are in the process of completing this requirement. Despite this, ethical considerations have been at the forefront of our evaluation process, and we have taken proactive steps to align our study with ethical research practices.

4 EVALUATION RESULTS

This section presents the results of evaluating music visualizations that did not follow our process and the two alternatives following our process. These alternatives served both to test and refine Thunder.

4.1 Initial Evaluation

Among the five pieces, three evoked predominantly positive emotions: peace and tranquility for *"Itsumo Nando Demo"*, happiness for *"Country Road"*, and motivation for *"Sanpo."* One piece, *"The Sixth Station,"* predominantly evoked negative emotions, such as loneliness and fear, while *"Mononoke Hime"* elicited both negative and positive emotions, including melancholy, sadness, and confidence (see Table 1).

Table 1: Word association of each musical piece

Music	Words (Researcher 1)	Words (Researcher 2)
Itsumo Nando Demo	Tranquility, hope, serenity, peace, friendliness	Peace, tranquility, joy, calm
Country Road	Cheer, happiness, fun, optimism	Tranquility, adventure, happiness, journey
Sanpo	Confidence, motivation, triumph, courage, pride	Journey, heroic, confidence, happiness, motivation
Mononoke Hime	Sadness, suffering, melancholy, acceptance, courage	Calm, melancholy, fear, insecurity, inner peace, confidence, adventure
Sixth Station	Insecurity, loneliness, confusion, destruction	Fear, loneliness, sadness, uncertainty

The analysis of PrEmo (see Figure 2) predominantly revealed a range of positive emotions, with only 11.1% of negative responses. This consistency in predominantly positive emotions suggests a gap in the emotional expression of the musical visualizations, potentially lacking elements to capture and convey the feelings evoked by the music. Even in more melancholic and emotive compositions, there was a lower correspondence between the emotions conveyed by the music and those elicited by the visualizations.

For example, the song *"The Sixth Station"* presented results of negative emotions in the free word association, but its PrEmo results were mainly positive. Additionally, *"Mononoke Hime"* presented a balance of positive and negative emotions in word association but showed mostly positive emotions in PrEmo. The visualizations lack elements to convey negative emotions, even when the corresponding music has a more negative tone. However, the songs *"Itsumo Nando Demo"*, *"Country Road"*, and *"Sanpo"* were linked with positive emotions, as reflected in the majority of PrEmo responses falling within the positive spectrum. This illustrates that visualizations effectively convey positive sentiments when addressing positive emotions, suggesting a greater facility in eliciting emotions within this spectrum.

Regarding the overall experience, the IMI-TEQ-Br Interest/Enjoyment (IE) scale presented a mean score of 6.32, close to the maximum value of 7, indicating a positive reception of the musical

Figure 2: PrEmo results from the Initial Evaluation

visualizations by the target audience (see Table 2). Nevertheless, we underline that due to the presentation environment where the evaluation was conducted, it cannot be completely affirmed that this interest and engagement are solely related to the visualizations.

Table 2: IMI-TEQ Br IE score Results

IMI-TEQ Br	Mean	Std. Dev.	Min	Max	Mode
IE1	6	1,317	2	7	7
IE5	6,46	1,022	2	7	7
IE8	6,38	1,016	3	7	7
IE10	6,35	1,087	3	7	7
IE14	1,67	1,578	1	7	1
IE19	6,41	1,117	3	7	7
Score (IE)	6,32	0,927	2,67	7	7

Regarding the UES-Br Short-Form results (see Table 3), the Focused Attention (FA), Perceived Usability (PU), Aesthetic Appeal (AE), and Reward Factor (RW) scores were calculated, and descriptive statistics were performed. As observed in the IMI-TEQ, the UES statistical analysis revealed consistent patterns in the results. The average of all scales was 4.39, close to the maximum value of 5. However, the FA scale presented the lowest mean, indicating that some participants may not have felt completely absorbed during the presentation, possibly suggesting a decline in engagement over time.

Table 3: UES Br SF score Results

UES Br SF	Mean	SD	Min	Max	Mode
FA	3.99	0.93	1.67	5	4.67
PU	4.41	0.99	1	5	5
AE	4.55	0.54	2	5	5
RW	4.61	0.71	2	5	5
UES	4.39	0.72	2	5	4.92

The comparison between word associations and evaluation results during the performance revealed some discrepancies between the word associations and the emotions perceived by the audience. Despite this disparity, the visualizations were well-received, as indicated by the high average IMI-TEQ-Br and UES-Br scores. Furthermore, although overall satisfaction with the visualizations was high, the FA scale of the UES questionnaire suggested potential lapses in audience engagement during the presentation, possibly indicating a decline in interest over time. These findings highlight the importance of enhancing music visual visualizations' emotional expressiveness and overall engagement.

4.2 Testing our process

To verify whether our adaptation of the process conveyed the emotions more effectively and refine the proposed steps, we applied an under-development version of Thunder to create two alternatives of the previously evaluated visualizations of "The Sixth Station." Our goal was to conduct a comparative analysis to determine if our method would yield results more attuned to the emotional essence of the music. This also helped us to refine our process by identifying possible gaps in the steps and the need to include or change techniques.

We started by mapping the emotions of the song by using the interactive map of [11]. We identified three music samples that were similar to the sound of *"The Sixth Station"*: samples **1808**, **1483**, and **219**, which all fall into the "Sad, Depressive" dimension. After that, each designer responsible for the alternatives conducted word associations evoked by the chosen music (*The Sixth Station*), resulting in the words described in Table 4. Then, the designers selected the main words to guide the emotional communication of each alternative, resulting in Table 5.

Table 4: Words associated with the music

Researcher	Words Associated
1	Insecurity, Solitude, Confusion, Sadness, Unknown, Anguish, Discomfort
2	Solitude, Resilience, Sadness, Passage of Time, Constancy, Passage, Transformation, Unknown

Table 5: Selection of words for the alternatives

Alternative	Words Selected
1	Solitude, sadness, anguish, ignorance, flowing lines, night, flashing lights
2	Loneliness, Sadness, Passage of Time, Constancy

Next, the researchers selected the music's key elements that would influence the visual interactive elements of the visualization. These key elements include beat, velocity, volume, and frequency. The combination of beat and music speed was chosen due to their shifts reflecting the varying moods within the music. This variation, alternating between slower and faster tempos, allows the listener to connect with the song's melancholic atmosphere and its intended message. Additionally, fluctuations in volume throughout the piece were essential in establishing emotional depth and contrast, capturing the listener's attention at key moments. The frequency of various instruments and melodies interacting with a

wide range of pitch levels contributes to the music's sense of depth and complexity.

4.2.1 Conceptualization of aesthetic aspects. To begin conceptualizing aesthetic aspects of the music visualization, designers gathered their ideas into mood boards representing the emotions indicated by the emotional mapping. The first mood board sought references primarily related to sensations of solitude and fear, seeking visual representations of water, flowing lines and trains, and flashing lights to establish a connection with the movie scene of the song. Additionally, it emphasized references to nighttime scenarios, resulting in a darker palette intended to enhance feelings of loneliness and sadness. Visual references from the movie scene in which the selected song is featured were also used to establish a sense of connection between the visualization and the film for the viewer.

The second mood board focused on the concept of loneliness and the passage of time, emphasizing word associations. The mood board reflects this choice by exploring sunset and dusk tones to symbolize the transition from day to night. Darker tones were used to evoke feelings of loneliness and melancholy. Furthermore, the mood board features images of translucent elements and overlapping circles inspired by the scene of the train passing underwater, as portrayed in the film. Visual references from the film were included, allowing audiences familiar with the work to identify more easily with the visualization.

4.2.2 Medium-Fidelity Prototype. The medium-fidelity prototyping resulted in two alternatives (see Figure 3).

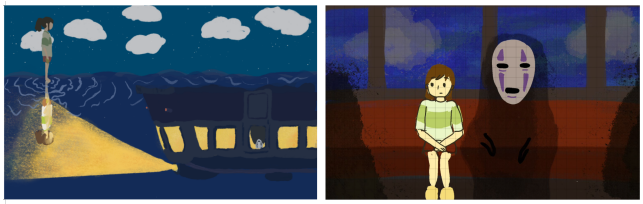

Figure 3: Medium-fidelity prototypes of Alternative 1 (left image) and Alternative 2 (right image)

After the directions given during the feedback session concerning the **emotional communication**, Alternative 1[2] had the following changes: (1) changing the character's expression according to the music, by lowering the head to give more intensity to the feeling of sadness. Alternative 2[3] had the following changes: (2) presenting gray clouds and a closed sky to make the landscape look sadder; (3) placing the character alone inside the train looking at the horizon with a more serious face, without introducing other characters to highlight the feeling of loneliness.

Regarding **aesthetic aspects**, the following changes were suggested for Alternative 1: (1) removing the train light response from the music beat to avoid visual discomfort and (2) placing the character more prominently to give her greater focus. For Alternative 2, the changes aligned with suggestions to enhance emotional expression, such as (3) making the color scheme darker and (4) portraying the character in solitude with a serious facial expression. The suggestions were incorporated into the medium-fidelity prototype, which then developed the high-fidelity version.

4.2.3 High-Fidelity Prototype. The high-fidelity prototyping resulted in two prototypes (see Figure 4).

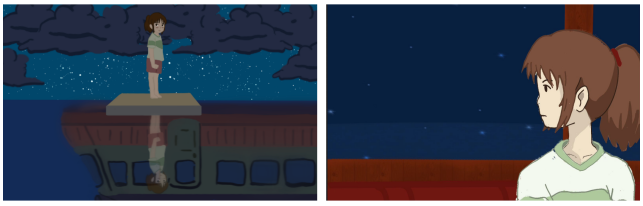

Figure 4: High-fidelity prototypes of Alternative 1 (left image) and Alternative 2 (right image)

Following the change suggestions from the feedback session, Alternative 1[4] maintained the concept of Chihiro alone, except for the arrival of the train, and surrounded by water. Concerning **emotional communication**, (1) Chihiro was placed face forward so the viewer could see her sad and scared expression, (2) the clouds gained a darker shade to appear as if a storm was approaching, creating a sense of fear, and (3) in the final moments of the music, when the song slows down, the image of Chihiro and her reflection changes with her lowering her head to intensify the sense of sadness. Gradually, other elements, such as star clouds and the train, disappear, leaving only Chihiro and her reflection, indicating her loneliness. Alternative 2[5] maintained the two parts of the visualization, but there were some changes based on the feedback session to convey the desired emotional aspects. Thus, in the first part of the visualization, (4) the scene would begin with a darker color palette to create a sense of fear. (5) The character Chihiro appears alone in the center of the train to indicate her loneliness and fear. For the second part of the visualization, (6) the focus would be on Chihiro's face inside the train, without showing other characters to increase the perception of her loneliness.

Regarding **aesthetic aspects** for Alternative 1, (1) the character was placed in greater focus, being positioned in the middle of the illustration and on top of a platform to give her more prominence, and (2) the train was maintained, but now only its reflection, representing that it is in the world of the dead, as in the movie's story, and its light was removed to avoid visual discomfort. For Alternative 2, the aesthetic decisions included: (3) as the music progresses, the clouds and sky would take on an even darker shade to represent the passage of time and the end of the day. Additionally, (4) the upper view of the train was changed to a side perspective to represent that the train was only going forward. For the second scene, (5) the clouds behind her would gradually dissipate, revealing the night sky and the shining stars that would synchronize with the music's beat.

[2]https://bit.ly/medfi-prototype-a1
[3]https://bit.ly/medfi-prototype-a2
[4]https://bit.ly/hifi-prototype-a1
[5]https://bit.ly/hifi-prototype-a2

Figure 5: PrEmo results from laboratory evaluation

4.3 Laboratory Test

The Laboratory Test included participants who met the inclusion criteria: they must be over 18 years old and available for an in-person test. Participants were recruited through social networks, resulting in five male and non-binary participants aged between 20 and 28. The participant selection method used in this research was convenience sampling, in which participants were invited because they would fit the profile and worked in the same laboratory. The research used a Free and Informed Consent Form and adopted measures to guarantee the collection and secure storage of data, ensuring anonymity and the participant's right to withdraw.

Comparing the emotions evoked in the word associations with the emotions indicated by PrEmo (Figure 5), the original visualization of *The Sixth Station* had divergent results. While the associations were of negative emotions such as sadness and loneliness, the PrEmo results were mostly positive, like "satisfaction," "hope," and "admiration," with some negative emotions like "shame" and "sadness," but less frequently. These findings mirror the evaluation results from the String Camerata presentation context, demonstrating a tendency for visualizations to convey predominantly positive emotions. This trend persists even without specific contextual influences, indicating a deficiency in effectively conveying negative emotions within the visualizations. Despite the underlying negative content of corresponding songs, the visualizations appear to lack elements that effectively evoke such emotions.

Both the alternatives effectively communicated negative emotions, such as sadness and shame, as expected by the designers. Alternative 1 was more successful in transmitting the associated emotions, with the main emotions evoked being "sadness" and "shame," both on the negative spectrum. Alternative 2 also evoked "sadness" and "shame" but presented positive emotions such as "fascination," "hope," and "pride."

When comparing the word associations conducted during the test with those previously performed by our research group, points of convergence were identified. For instance, the original *"The Sixth Station"* highlighted words such as "solitude" and "loneliness" in both evaluations.

Regarding the produced alternatives, both had positive results from the word clouds, presenting words close to those expected during the production of the visualizations. For example, "loneliness" and "sadness" in Alternative 1; and "time," "peace," and "solitude" in Alternative 2. This indicates that they were able to evoke the emotions that the researchers aimed to convey.

For the qualitative analysis, the interviews were transcribed and analyzed for content. Three categories were created: **Emotion** (1), which includes excerpts related to emotional communication passed through music and visualization, subdivided into (i) problems with communicating emotional aspects, (ii) compliments on emotional communication, (iii) suggestions for improving emotions, (iv) influence of the work on emotions, and (v) motivation of emotion; **Music** (2), which includes units related to the communication of musical elements and their synchronization with visualization, subdivided into (vi) communication problems of musical elements, (vii) compliments on musical element communication, (viii) synchronization problems, (ix) synchronization compliments, and (x) suggestions for improving the music; and **Aesthetics** (3), which includes units related to visual elements of visualization and their influence on attractiveness, focus, and engagement, subdivided into (xi) aesthetic problems, (xii) aesthetic compliments, (xiii) focus problems, (xiv) suggestions for aesthetic improvements, and (xv) influence of the work on aesthetics.

In the **Emotion** category, the choice of colors and visual elements significantly influenced participants' feelings. When these elements harmonized with the music, participants easily identified their emotions. For example, in relation to Alternative 1 one participant noted, "the tones of the animation, the colors of the animation, I can see a beautiful gray scale, with some shades of blue, but I can see that it's cold, I can see that there's a melancholy... the starry sky, the dark clouds, the scenery as a whole, they are melancholic." Conversely, misaligned elements broke participants' expectations, as one remarked, "I don't think it conveys how melancholic the child who's lost without their parents is here, you know? There's a whole weight on that."

Additionally, some participants who were unable to relate the emotions of the music and the visualization ended up associating the emotions felt during the test with those felt when watching the film. One participant mentioned, "So, I think the entire setting, its construction, refers to the movie [...]. I feel like this one makes a direct connection, and it ended up bringing me feelings from the movie, you know?". indicating that the emotions evoked were felt by the context of the film due to the lack of emotional expressiveness in the visualization.

As for the alternatives we produced, the content analysis indicated that the choices of visual elements met the researchers' expectations about the evoked emotions - sadness, loneliness, and melancholy. Excerpts from Alternative 1 and 2, respectively, illustrate this: "I can see that there is a melancholy... the starry sky, the dark clouds, the scenery as a whole, they are melancholic" and "And the second one I found lonely, perhaps because I was darker because… in the other, she was accompanied. And here she is alone. The time is because I see a transition in time as the sky darkens."

In the **Music** category, visual elements influenced how participants perceived the music, potentially intensifying or reducing the impact of certain moments. For instance, one participant noted, "In this one, I think it was the one that gave me the most sense of sound. You know, seeing it flashing, vibrating, and increasing," referring to Alternative 1. However, these elements can also be

confused if they are not harmonized with the music. As another participant mentioned, "But there are some points that bother me, like her blinking and how everything moves and doesn't have a certain homogeneity," referring to the original visualization.

Additionally, when elements representing the music were integrated into the visualization, such as the water waves representing the frequency of the music in Alternative 1, participants showed more interest without considering them a distraction. This is reflected in the statements: "They [frequency waves] are the manifestation, very clever indeed, of sound waves. Just like a mechanical wave propagates in water, so does sound. So, there's this interesting play of meaning" and "It's easier to have something small like just the waves, which I see matches the music than to add a lot of things and see that there's something that doesn't match, that bothers me."

In the **Aesthetics** category, we noticed that, as in the **Music** category, participants demonstrated greater preferences when visual elements were inserted into the context of the visualization illustration, blending harmoniously without causing visual discomfort. However, elements outside the context caused visual discomfort and were deemed unnecessary, as one noted, "It's easier to have something small like just the waves, which I see matches the music, than to add a lot of things and see that there's something that doesn't match, that bothers me."

Thus, we understood that the selection and placement of elements within the visualization, alongside the overall context of the illustration and their alignment with the movie's storyline and music, are crucial for effectively communicating emotions to the viewer. When these elements are not seamlessly integrated into the visualization or appear out of context, presented solely in a graphical manner, viewers may struggle to associate emotions and become confused about which element to focus on. Furthermore, the choice of elements not only influences emotional communication but also impacts the conveyance of musical aspects within the song. When the animation's movements are not synchronized with the music, viewers may experience confusion and discomfort due to the overload of information.

The results showed that the alternatives, in general, communicated the expected emotions well and were well-received by the public. Therefore, improvement decisions focused on extracting the most positive aspects from each visualization to develop a single, cohesive version. From Alternative 1, participants appreciated the dark color palette that reinforced the song's feeling of melancholy; the change of expression by the main character that intensified the sense of sadness; and the choice of interactive elements to represent musical elements, such as the water's waves to represent the frequency. As for Alternative 2, the participants liked the concept of scene transitions, the focus on the main character's expression during the close-up to create a deeper connection with her, and the shift in time from sunset to night, which created a melancholic atmosphere.

During the feedback session, we discussed these points to incorporate the best aspects of both alternatives into the final version. We decided to use the dark color palette from Alternative 1 instead of the pastel palette from Alternative 2 to evoke stronger negative emotions, such as solitude and sadness. We also adopted the scene transitions concept from Alternative 2 to create smoother transitions. We included the element of Chihiro's changing emotion, specifically her lowered head from Alternative 1, as it significantly emphasized feelings of sadness among participants. Also, we integrated the close-up shot from Alternative 2, where Chihiro's expression is highlighted, to facilitate a stronger emotional connection and enhance participants' ability to relate the visualization to the movie.

4.4 Implementation

The implemented version consists of coded interactive animations, produced using *Processing* version 4.3, that will dynamically respond to the musical elements of the accompanying music using a microphone to capture musical information for interaction with visual elements. This implementation will later undergo a field test, as the concluding phase of our study, to validate this alternative using the same techniques we used in the initial evaluation phase.

5 THUNDER: A DESIGN PROCESS FOR EMOTIONALLY ENGAGING MUSIC VISUALIZATIONS

Thunder was designed based on a user-centered iterative process, combining the theoretical basis of Almeida et al.2021 with empirical data into a practice-oriented and effective design process.

We conducted preliminary evaluations and user testing to inform the development of the Thunder process. The two alternative visualizations conducted with Thunder were much more successful in evoking the intended negative emotions, such as sorrow, shame, and loneliness, as confirmed by the PrEmo results and the word associations. The comparative analysis showed that Thunder can make the visualization more emotionally similar to the target song.

Thunder is a four-step structured, iterative approach to designing music visualizations that elicit intended feelings from a target song. Its main differences from other approaches are emotional mapping and animated prototyping to assess emotional communication. Thunder's goal is to supply a practical framework for creating visualizations that effectively improve the emotional impact of the music. The remainder of this section details the final form of Thunder.

5.1 Step 1 - Conceptualization: Begin by Understanding The Emotions

Conceptualization has two substeps: Music and Interaction Decisions and Style Decisions. The Music and Interaction Decisions step begins the process, where designers choose the music that will be used to produce the visualization. This is followed by deciding on the emotional communication that will guide the visualization's aesthetic and evaluation decisions and, finally, choosing which elements of the music will interact with the animation.

First, it's necessary to identify the emotional content of the target song to decide on the emotional communication to be followed. We suggest a combination of techniques that can be used for this matter. *Free association* of words, in which the designer can establish links between the music and their ideations, followed by *the categorization of the music* based on the interactive map proposed in the study of Cowen et al. (2020). After that, the list of words generated in the free association and the list of emotions raised on the

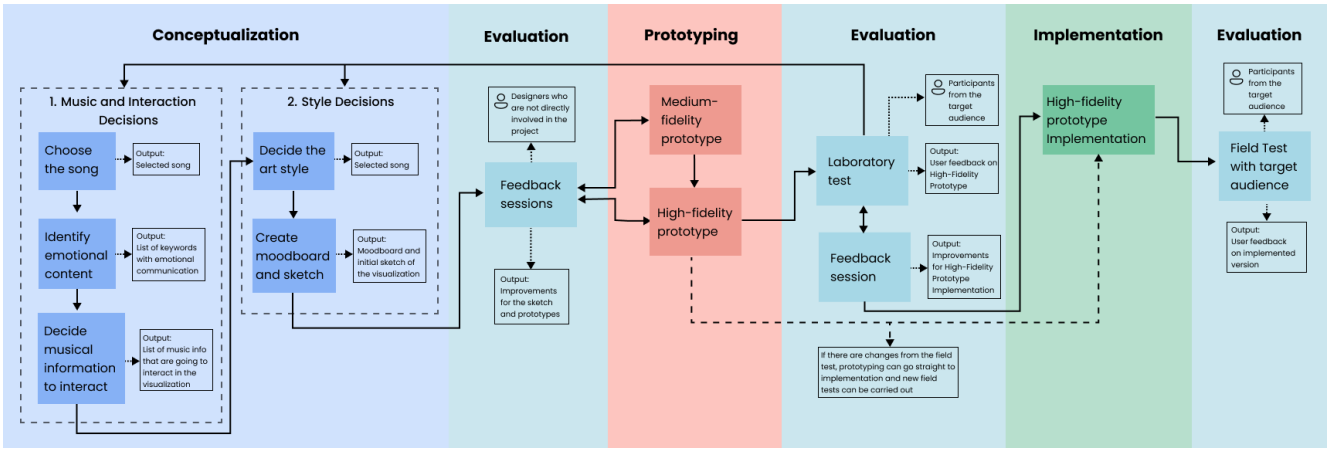

Figure 6: Thunder: a process to develop emotionally engaging music visualizations

interactive map must be combined to select only the visualization's main communication.

Then, designers must decide the musical information that will be used as input for the visual elements of the musical visualization to interact. This will help them select the musical elements that will interact in the visualization to convey those emotions successfully.

Aspects such as rhythm, speed, volume, frequency, and representation of instruments and voices can be chosen. Designers do not need to stick to theoretical musical knowledge when choosing this information; they can limit themselves to the aspects that are most relevant to the chosen music and that can generate constant interactions within the projected visualization.

In the Style Decision step, the designer first decides on the artistic style to guide the music visualization. This decision must be rooted in the emotional analysis of the music and the specific emotions that the designer wants to convey. The style will act as a visual language through which designers should develop the visualization's color palette, shapes, textures, and overall aesthetic into a cohesive and emotionally resonant experience. It is a creative decision, though, that has to be guided by the feelings of the underlying music. For instance, to convey the sense of sadness and melancholy, designers could use something subdued and atmospheric in style with muted colors, soft textures, and slow, flowing movements, or even think of animation with fading watercolors or a figure who walks alone in the misty landscape. To convey mystery, it could be a darker, more abstract style with deep shadows, geometric shapes, and unpredictable movements, maybe with shifting fragmented imagery or a landscape slowly revealed through layers of shadow.

Then, designers create mood boards and sketches, combining the visual information to determine which visual elements will represent the previously selected interactive music information. For the mood board creation, it is necessary to define (1) visual information on the defined artistic style, (2) visual information representing the previously aligned emotional communication, and (3) the context in which the music is inserted – if the music is part of a movie or game soundtrack, the mood board should contain visual information of the moment the music is played, like scenarios or characters involved. Based on the mood boards, designers create initial sketches of the visualization, connecting visual references gathered. Finally, as determined earlier, the visual elements from the sketches are chosen to reflect the musical aspects that will interact effectively.

5.2 Step 2 - Prototyping: Iteratively Create Alternatives to Embody The Concept

Initially, designers create animated medium-fidelity prototypes based on the initial sketches made at the end of the conceptualization stage. We suggest creating alternative prototypes by different designers to capture the nuances of the music's emotion better. These alternative prototypes might later be merged into a single solution, or designers might choose among one of them. It's necessary to animate these prototypes to better represent their interaction with the music elements before implementing them.

For the prototype, designers apply the color palette generated from the established mood board, along with a few frames representing the music's interactions with the visualization, which should be synchronized with the background music.

Prototyping is an iterative step. Following the creation of medium fidelity prototypes, designers conduct a feedback session (i.e., an iterative step with the Evaluation), preferably involving designers who are not directly involved in the project, to assess whether the prototype reflects the projected emotional communication, whether aesthetic choices facilitate easy comprehension of this communication, and whether the visual elements chosen for interaction align with the musical information chosen for interaction. After the feedback session, designers should have a list of positive aspects and improvement points.

Following modifications to the medium-fidelity prototype, a high-fidelity prototype should be produced with maximum fidelity to how the implemented version should look. To achieve this, the designer refines the visual elements and animates the entire music, clearly indicating the interactive elements of the visualization with the music. Subsequently, this prototype will undergo lab testing to validate the emotional and interactive aspects with users from the visualization's target audience and, if necessary, will return for refinement based on the test results.

5.3 Step 3 - Implementation: Give Life to The Idea

The Implementation phase involves translating the high-fidelity prototype into an animated music visualization that dynamically responds to the target music, which can be played live or in a different arrangement from the recorded version. This includes translating the high-fidelity prototype into code using programming languages, libraries, and frameworks suitable for animation and music processing. Musical information can be inserted directly into the code and programmed to interact with the visual elements, or it can be inserted via microphone pickup.

Implementation is also an iteration. After implementation, the visualization must undergo an evaluation through a field test with the target audience.

5.4 Step 4 - Evaluation: Evaluate Emotion Communication and Design Choices At Each Step

Evaluation has three substeps: feedback sessions, laboratory tests, and field Tests. The two first substeps are iterations of the prototyping step, and the last one is an iteration of the implementation step.

Feedback sessions are conducted with the designers of the prototypes and external designers and should focus on validating the prototype's emotional communication and aesthetic decisions. These sessions can be implemented as meetings (face-to-face or online), where designers should start by watching the prototypes and then conduct a design critique, systematically giving their impressions, raising positive and improvement points on emotional, aesthetic, and interactive aspects. Later, the internal designers can delve deeper into each point or suggest new analysis points for the external designers. Adjustments to the prototypes are made based on feedback, focusing on maintaining the emotional communication defined in the first phase.

The laboratory test should be carried out after the high-fidelity prototype has been completed since it will have to be applied to the target audience, and they should have little or no idea that it is an unimplemented prototype. In this test, the evaluators should collect the user's emotional perception during and after watching the visualization and evaluate the interactive elements designed. For this step, we suggest a combination of three techniques: *free word association, the PrEmo scale, and a semi-structured interview.*

The free association of words takes place during the presentation of the prototype so that the participant can freely and individually take note of what comes to mind when seeing the musical visualization. After presenting the prototype, participants answer PrEmo to collect the user's emotional response to the visualization. Finally, a semi-structured interview is carried out to delve deeper into possible words or emotions associated with the visualization that were confusing because they were outside the curve of the projected communication, as well as being able to explore which specific visual elements led users to associate with a particular emotion and collect feedback on the interaction of the visualization with the music.

After the laboratory test, the evaluators and designers should have a final feedback session to identify the positive points and improvements raised in the test. If the communication evaluated differed from that design, they should decide to return to the conceptualization stage to refine the aesthetic aspects of the emotional design. If the emotional communication is as designed, the improvements listed in the evaluation should be applied to the high-fidelity prototype, which will then go on to the implementation stage.

Finally, after implementation, the functional musical visualization should be evaluated in a field test to obtain the emotional perception of users outside of a controlled environment. For this stage, we suggest the application of PrEmo, after the presentation of the musical visualization, IMI-TEQ Br [37] to measure audience motivation after watching it, and UES-Br [34] to measure their engagement.

6 RELATED WORK

This section delves into works that have contributed to providing tools for creating music visualizations across different contexts. As illustrated in Table 6, these studies offer insights into a spectrum of processes, guidelines, frameworks, and pipelines, each tailored to address specific objectives within this domain. By examining these contributions, we comprehensively understand the current landscape of music visualization research.

Almeida et al. (2021) proposed an experimental design process informed by prior research on animation, music visualization, and principles of Design Thinking, they collected in a systematic review on animated music visualization, which later gave rise to an experimental design process informed by prior research on animation, music visualization, and principles of Design Thinking [3]. Their process comprises three iterative phases: synthesis, which deals with choosing the musical elements to be visualized; ideation, involving user-defined representation of concrete moments in music through sketching and prototype development; and validation, during which prototypes are developed into digital animations by experts and analyzed if they conform to the initial goals. While this approach shares some similarities with the emphasis of the Thunder process on iterative design and validation, the aim, in this particular case, differs in the communication of emotions. More precisely, we apply techniques such as word association exercises related to the music and visualizations, graphical tools for representing viewer emotions, and in-depth interviews to find and appraise emotional links between the visualization and the music.

In Holm and Siirtola (2012), the authors developed guidelines for creating systems to generate musical visualizations based on two software tools: Espectromusic, a multiplayer game that creates dynamic labyrinths from live music, and Mandrit, a rhythm analysis tool that visualizes musical structures. These tools process MIDI data to produce dynamic and static visualizations that convey musical and sound information. Through prototyping, the team identified challenges in visually representing musical information, leading to insights into the Computational Visualization of Music and the development of five guidelines: researching musical information for visual communication using user-centered techniques and participatory observation, categorizing and selecting suitable visualization types based on research findings, employing computational resources to create automatic visualizations by extracting,

treating, and filtering musical data, using a design process comprising ideation, prototyping, and evaluation, incorporating feedback and fidelity tests, and sharing graphical results with the community to foster cooperation in this field. While these guidelines provide a useful framework, they do not offer a detailed process for development. Thunder incorporates guidelines 4 and 5, emphasizing iterative design, evaluation, and result sharing. We differ by establishing a concrete process with suggested techniques, focusing on emotional communication rather than purely technical aspects, thereby enabling emotional connection through visualizations.

Wang et al. (2023) presented a music visualization system, which translates musical input to dynamic facial expressions reflecting the emotional content of the music, using Action Units (AU) to animate a virtual avatar in real-time for enhanced music experiences, especially for individuals who are hard of hearing. Their work shares our focus on the emotional conveyance of information, but our approach departs from theirs in their reliance on facial action coding. In the Thunder process, we explore a more general approach to emotional translation that is not driven by any specific technology—such as the elaborate, detailed anatomical segmentation of facial expressions into AUs.

Finally, Cantareira et al. (2016) proposed MoshViz, a novel visualization framework focusing on the analysis of specific musical instruments to achieve insight into the musical structure, harmony, and melody. The authors draw attention to the limitations of traditional tools for music visualization, mostly focused on visual metaphors representing the music sheets and the piano rolls. While these representations capture important musical information, they often fail to sufficiently represent patterns and structures like rhythm and harmony, which users must infer themselves. Although our study has a different priority with respect to emotional communication, it is important to represent the elements of melody and harmony. This forms part of our conceptualization process by careful selection of elements to be visualized and how they should be represented to elicit emotions from the viewer. In contrast to MoshViz's view of comprehensive musical information, we focus on communication through the visualization of key musical elements, using animation and illustration to promote a deeper relationship to the emotional story of the music and, in addition, a structured design process for guaranteeing the accomplishment of emotional conveyance.

While the existing body of research offers valuable insights into technical and overall aspects of music visualization development, our work, in contrast, introduces a comprehensive and detailed framework specifically designed to facilitate the creation of music visualizations that prioritize emotional communication with the audience. We achieve this by outlining a clear step-by-step process with well-defined techniques tailored to evoke and analyze emotional responses, distinguishing our contribution from previous efforts.

7 DISCUSSION

In this section, we present the main challenges and insights from the development of Thunder, as well as their implications for promoting well-being and emotionally engaging visualizations.

7.1 Challenges of Designing Emotionally Resonant Music Visualization

Emotions are subjective by nature and are created by individual experiences and cultural backgrounds, making it hard to create visualizations that elicit similar emotional feelings universally [11, 24]. This subjectivity makes selecting and synchronizing visual elements with musical elements very important. Thunder mitigated this complexity due to its iterative nature, which allowed continuous refinement based on feedback and evaluations. However, even with iterative refinement, a consistent emotional response among the audiences remains elusive for future research. This creates a need for more robust methods to understand and account for individual differences in emotional perception.

Another critical aspect involves balancing aesthetic decisions with functional elements that interact meaningfully with the music. While the visual appearance is critical to audience engagement, it should not overwhelm the interactive elements that represent the musical components. This balance is particularly challenging during the high-fidelity prototyping phase of Thunder, where designers must ensure the visualization remains visually captivating and functionally informative. This aligns with findings from Holm and Siirtola (2012), who emphasized the need for harmony between visual and musical elements in their guidelines for music visualization systems. Furthermore, it is important to consider the excess of interactive elements competing within the visualization, a concern already noted in the literature as potentially affecting audience focus [5]. This aspect may be related to the lower scores of Focused Attention observed in the UES-Br applied to the initial visualizations (before applying Thunder), which suggests that a balance between visual richness and clarity is essential.

Still, another challenge in this context is the inherent subjectivity introduced when a single designer creates a visualization. The designer's personal, emotive perceptions and experiences can't help but filter through the visual elements and their synchronization with the music. This can result in a biased representation of the intended emotional impact. This could be why the emotional response some visualizations provoke might be distorted by the audience, as the feelings and sentiments of the designer would not align with the diversified emotional landscapes of different users. To decrease this type of subjectivity, in our process to develop Thunder, we included two designers and two researchers who were not part of the design process to collect feedback from different perspectives. We advocate that a multi-disciplinary team approach is necessary to design—where the psychology domain, musicology, visual arts, and user experience design come together to maximize the universality of emotional communication.

7.2 Music, Emotions, and Well-being

The complex interaction between well-being and emotions has been extensively documented across various academic fields, demonstrating the influence of emotions on human experiences and well-being [15, 43]. Emotional well-being is a key factor in mental health, influencing cognitive processes, behavior, and quality of life [21, 26]. Understanding the mechanisms that underlie emotional responses and their effects on well-being can inform various applications.

Ref	Proposal	Context	Contribuition
Almeida et al.	Experimental process	Design of animated musical visualizations	Design model of creating animated musical visualizations based on design thinking and other processes.
Holm and Siirtola	5-step guideline	Generating music visualizations based on musical information	5-step guideline for creating systems to generate musical information
Wang et al.	Pipeline	Music visualizations for communicating emotions	Music visualization system that translates music input into facial expressions
Cantareira et al.	Framework	Creating music visualizations to represent musical information	A framework that facilitates the visualization and understanding of music renditions
Our work	Design Process	Creating music visualization to convey emotions	A Design process for creating music visualization that convey the emotional content of the music

Table 6: Related works

Music plays a significant role in this dynamic as a powerful emotional stimulus. Its ability to evoke deep emotional responses and enhance well-being is well-established in research and practical contexts [28]. The structural elements of music—tempo, melody, harmony, and dynamics—interact with listeners' cognitive and affective systems to evoke a wide range of emotions, from joy and relaxation to sadness and tension [23, 45].

Thunder is aligned with that perspective because it considers music's intrinsic emotional quality to help develop visualizations that enhance the emotional depth of interactive applications. This is supported by the Self-Determination Theory (SDT) [44], a psychology theory widely used in HCI that focuses on intrinsic motivation, autonomy, and competence for well-being. Thunder can foster a sense of intrinsic motivation by creating immersive experiences that resonate deeply with users. It encourages users to engage with the visualizations out of genuine interest and enjoyment. This is particularly relevant in digital storytelling and artistic settings, where the effective integration of music and visuals can significantly enhance the story's emotional impact and help communicate an underlying message.

Furthermore, Thunder can be particularly beneficial to improving the sense of autonomy in contexts with limited access to music, such as for individuals with hearing impairments, contributing to their overall well-being and integration. Our research corroborates the work of Pouris and Fels (2012) and Fourney and Fels (2009), that highlight the importance of accessible music experiences for the deaf and hard-of-hearing communities. By enhancing the emotional expressiveness of music visualizations, Thunder offers an accessible way to experience the emotional content of music through visual stimuli, making the benefits of music more inclusive.

7.3 Going Beyond to Assess Audio Impact on Well-Being and Experience

Sound is a potent force in shaping emotions and experiences within immersive environments, ranging from musical visualizations to games and virtual reality (VR). While it can enhance engagement, immersion, and well-being, it can also manipulate, induce anxiety, or divert attention for exploitative purposes. Recognizing this dual nature is crucial for responsible immersive experience design.

Applying SDT principles to audio design using Thunder suggests that catering to users' needs for autonomy, competence, and relatedness can enhance their engagement and well-being. For example, customizable sound settings, clear feedback mechanisms, and audio features that foster social interaction can all contribute to a more positive long-term user experience.

Generalizing research findings beyond specific application types, such as musical visualizations and VR experiences, helps mitigate potential biases and provides a more comprehensive understanding of the interplay between audio, user experience, and immersive design. Future research should employ mixed-methods approaches to measure and compare audio's impact on UX across diverse applications and contexts. This includes examining how audio interacts with UX in varying noise levels, distraction, immersion, and social interaction scenarios. Additionally, research must consider a diverse range of participants with varying demographics, preferences, and experiences. Statistical analysis can then be used to test hypotheses about the relationship between audio characteristics, UX, and well-being constructs.

The relentless pursuit of engagement in various immersive experiences, from games to VR, often overshadows the critical role of user experience in promoting well-being. This focus on "engagement at all costs" can neglect long-term impacts. One step toward overcoming this scenario is a deeper understanding of how audio influences user emotions, behaviors, and mental states.

We must move beyond superficial metrics and evaluate UX through a lens that prioritizes both immediate enjoyment and long-term well-being.

8 LIMITATIONS

Thunder is a promising approach to designing emotionally appealing music visualizations but has some limitations. Firstly, emotional perception is subjective in nature and, therefore, is likely to vary from one individual to another on account of cultural background, experience, and taste. Hence, the process cannot guarantee the complete absence of discrepancies between the intended emotional communication and user experience. Secondly, our results are based on a restricted collection of musical pieces and a non-probabilistic sampling. Other genres and styles of visualization could and may need special handling to clarify their emotional content.

9 CONCLUSION

This paper presented Thunder, a design process for creating music visualizations that effectively communicate the emotional essence of music and foster peoples' well-being. By integrating techniques for emotional communication, user-centered design, and iterative feedback, our approach addresses gaps in existing methods and provides a structured framework for designers. Our findings highlight the importance of aligning visual elements with the emotional tone of the music and demonstrate the potential of music visualizations to enhance user engagement and emotional experience. However, Thunder has some limitations, including the subjective nature of emotional perception and limited music sampling, which can lead to discrepancies in user experience and may require adaptations for various genres and visualization styles. Our study contributes to the growing field of music visualization by providing a detailed process that can be applied across various interactive media and digital contexts, not only enhancing the aesthetic appeal of music visualizations but also deepening their emotional impact, offering new opportunities for creators in entertainment, education, art, and therapeutic applications.

Future work should focus on expanding the application of our design process to different musical genres and visual styles, exploring its adaptability and effectiveness in diverse contexts. Additionally, further research could investigate the long-term effects of emotionally resonant music visualizations on user well-being and emotional health, building on music's therapeutic potential. By continuing to refine and expand our approach, we aim to contribute to the evolving landscape of interactive media and enhance the role of music visualizations in enriching human experiences.

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