Exploring Real-Time Interfaces With Sensory Percussion

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Figure 1: Simulated popcorn rigidbodies interact with a model of a drum

Abstract

Synchronous feedback, such as a teacher's spoken comments while students play, is important for music education. The ephemeral nature of sound makes this feedback critically important, yet difficult to communicate. In response, we present VESPer, a library integrating EVANS Hybrid Sensory Percussion with Unity to create real-time interfaces for percussionists, and etudes showcasing different designs for synchronous feedback. We provide a preliminary exploration of VESPer's role in percussion practice through qualitative case studies by the first author. We discuss considerations for *relevance* and *legibility* in visualizations of synchronous formative feedback, and in turn, scaffold the use of real-time interactivity to give percussionists deeper insights when practicing.

Keywords

Musical interface, controller, MIDI, game engine, Unity, Sensory Percussion, percussion, pedagogy

1 Introduction

Percussion has been used for millennia in communal, military, and religious contexts. In the 1970s, electronic drum controllers began to take shape [7]. Eventually, hybrid percussion emerged, incorporating triggers and sample pads played with sticks to blend acoustic and electronic sounds [9].

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A modern example of hybrid percussion is EVANS Hybrid Sensory Percussion (EHSP), a collaboration between the drumhead company EVANS and the electronics company Sunhouse. Much like a set of drum triggers, EHSP uses sensors that attach to acoustic drums. These sensors detect multiple playing zones on each drum and differentiate among techniques like stick shots, rim knocks, and dampened notes. Users can map zones and techniques to different sounds using the Sensory Percussion 2 software, which can trigger samples, send MIDI data, and manipulate effect parameters like reverb tail length and delay feedback percentage. Prior work uses drum triggers to control live video and lighting systems [18, 19], but this work emphasizes live performance rather than practice and educational settings.

Music education can take many forms, but one common component is constructive feedback. This often occurs as *synchronous formative feedback*, i.e., the comments given to a student during or immediately following the completion of an exercise [14]. However, the emphemerality of sound poses challenges. Feedback after the fact requires musical memory skills, while true simultaneous feedback often necessitates that teachers raise their voices, which conflicts with students' abilities to perform expressively.

Towards improving experiences of synchronous formative feedback for practicing musicians, we explored the usage of EHSP's sensors and its minimally invasive role as an add-on to existing instruments. We demonstrate descriptive tools for percussion practice and pedagogy that use real-time visuals for constructive feedback. Our research questions are:

RQ1: In what ways can the real-time nature of game engines support music pedagogy and practice?

RQ2: How might we design interfaces that use percussive controllers as input devices?

Our contributions include: (1) the open-source VESPer (Visual Expression for Sensory Percussion) library integrating EHSP, Open SoundControl [10], and the Unity game engine; (2) etudes showcasing applications for percussion teaching, practice, and performance; and (3) case studies illustrating the first author's practical experiences with VESPer as a working musician. We discuss how real-time interfaces can impact music pedagogy and share transferable guidelines for making visual feedback relevant and legible to percussionists.

2 Related Work

2.1 Hybrid Instruments

EVANS Hybrid Sensory Percussion (EHSP) is a hybrid instrument, a topic extensively studied in NIME [4, 13]. Its hardware clips onto acoustic instruments, making it preferable performers desiring tactile feedback. While some hybrid instruments use signal processing to transform or alter acoustic sounds, EHSP and others use MIDI to couple with digital technology. MIDI is advantageous because it is an interface protocol, not a sound-producing system.

By translating physical inputs into digital software, MIDI enables the use of hybrid instruments as input for contexts beyond sound production. This technique has gained popularity on YouTube and Twitch, where creators are speedrunning *Super Mario 64* on electronic drum kits [6], programming using an acoustic guitar with pitch detection software [3], and using a niche bongo controller as a keyboard replacement [12]. Musical controller inputs often map to single button presses or incremental mouse movements and, in turn, are novel for their theatrics and re-appropriation.

Building on using instruments as inputs to multimodal media, we apply EHSP's hybrid instrument input into the Unity game engine for musician-centered feedback.

2.2 Engines for Real-Time Audio and Visuals

Using game engines for visualization and interactive composition is an area of interest in NIME. Prior work focuses on sound: extending engines' sonic capabilities [1], generating 3D visuals from sound [16, 20], or creating sound-based games [2]. This body of work explores how to process input and modify output in real time. This makes it distinct from, say, 3D animations created to accompany a fixed media piece. Adriana Sa emphasizes this by using a "fungible audio-visual mapping," where musical events result in predictable and unpredictable consequences [16]. However, this is less desirable in educational settings, where consistency is often a priority.

We build on prior work to create real-time interfaces that mediate pedagogical feedback, which we describe next.

2.3 Feedback in Music Pedagogy

Music educator feedback varies significantly with teacher training and experience [8]. Lisa Martin explains that *synchronous formative feedback*, comments provided immediately after a segment of playing, is important for music education and typically the most common format [14]. Martin advocates for a model based on the *objective* or current learning goals, an *evaluation* of a student's current relationship to that goal, and the *action* that will bring the student closer to achieving that goal. However, the co-occurrence of audible spoken feedback and performance can necessitate frequent stops or raised voices, which can be frustrating for both students and instructors.

Self-assessment is also key to music pedagogy [11]. As personal recording devices, like smartphones, have become widely available, students can self-record their playing. This splits the learning process into a recording phase and an evaluation phase, which is non-ideal if the recording system is cumbersome to navigate or scroll through. Videos also use substantial device storage, especially when percussionsts need high frame rates to analyze their practice.

Next, we show how our artifacts provide synchronous feedback that alleviates the drawbacks of co-occurring audio and file management, as well as expand opportunities for musician-centered interfaces.

Figure 2: A Sensory Percussion setup, featuring a snare drum, the EVANS Portal, and a laptop running the Sensory Percussion 2 software application

3 System: VESPer

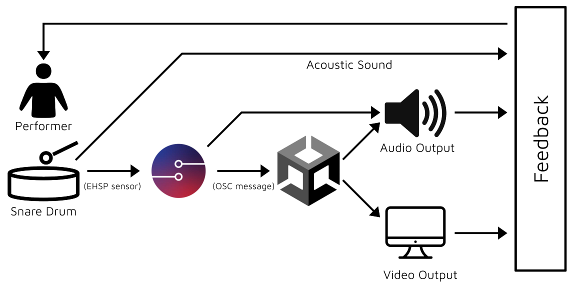


Figure 3: Diagram of VESPer inputs and outputs

3.1 System Overview

VESPer (Visual Expression for Sensory Percussion), our open-source library, uses Open SoundControl (OSC) to integrate EVANS Hybrid Sensory Percussion with the Unity game engine.

Figure 3 shows the flow of information through the system. The performer provides input by striking the snare drum, which produces sound and tactile feedback. The signal from the drum is sent via the EHSP sensor to the EHSP software. EHSP produces audio output and also sends zone and velocity to Unity via OSC. Unity produces additional audio output and real-time visuals.

3.2 Implementation

The Sensory Percussion 2 software application natively supports MIDI and Open SoundControl (OSC) [22] routing. The latter was used to send MIDI messages between EHSP and Unity, similar to a method used by Trolland et al. [20].

We used Unity due to its prevalence in the games industry[1] [23] and NIME [1, 20]. EHSP sends OSC messages via User Datagram Protocol[2], which Unity receives using a dedicated handler running on its own thread (based on a C# script by Thomas Fredericks [10]). The handler logs timestamps (in ticks) associated with each input[3]. A `GlobalData` class maintains information about the OSC port and OSC address. In each scene, a GameObject manages the OSC connection. Scripts can create references to this GameObject and add listeners that respond to any OSC messages using the address specified in `GlobalData`. These scripts are typically based on a prototype handler which contains an overridable method for handling note input that takes three parameters: command message, MIDI note number, and note velocity. Note mappings are handled within EHSP, where MIDI notes are assigned to different playing zones and techniques (collectively called "timbres" within EHSP).

4 Etudes

Our etudes demonstrate VESPer's potential to support teaching, practice, and performance. (See Appendix A for videos.)

4.1 Practice Aid: Grapher

The Grapher (Figure 4) visualizes inter-onset intervals, allowing users to see note density in their playing over time. The space between notes is converted into vertical position, while note velocity is converted into color. The graph values update in real time with the user's performance.

The Grapher can be a diagnostic tool for students and teachers. Potential applications include self-assessing the evenness of an open roll, visualizing unquantized or flexible rhythms, and practicing grace note consistency. These last two scenarios are typically difficult to practice because they are not locked to a metric grid. Therefore, the Grapher's visualization could help users identify tendencies in their own playing (e.g. a gap between the third and fourth notes of a four-stroke ruff) and adjust if desired.

4.2 Pedagogical Game: Table of Time

Table of Time (Figure 5) is a well-known exercise for practicing even playing across varying subdivisions [5, 17]. Typically performed with a metronome at a slow tempo, the player subdivides the beat in 2, then 3, then 4, and so on. In this etude, players must execute a new tuplet every eight beats; this real-time feedback can be of interest to advanced players seeking precision and accuracy.

Table of Time uses C#'s `DateTime` class to associate precise timestamps with each input; the high precision required in this game influenced the inclusion of this timestamp as a system design choice. The etude is biased towards accepting late inputs as accurate to account for human reation time and increase perceived fairness; a more robust calibration system is future work.

Table of Time also uses Unity's audio capabilities; the metronome pulse and game sounds are played using Unity's `AudioSource` component. EHSP can also be configured to trigger samples simultaneously with the user's performance.

4.3 Joyful Catalyst: Popcorn Visualizer

The Popcorn Visualizer (Figure 6) shows inputs as bouncing popcorn. Unlike Table of Time and Grapher, which are targeted practice tools, the Popcorn Visualizer imparts a sense of amusement and could be an audience-facing projection. Each note on the drumhead instantiates a new popcorn piece and applies a vertical physics force from an in-world surface. Different zones on the drumhead correspond with different in-engine surfaces.

This etude applies Unity's physics system. Each popcorn piece has a `Rigidbody` component and a convex version of the popcorn model as a collider. The Popcorn Visualizer also applies EHSP's capabilities for tracking velocity and playing zone. Whereas Table of Time invites users to modify input, the Popcorn Visualizer represents a largely one-way cause-effect relationship; the exact behavior of the popcorn is determined by the physics system moreso than player.

4.4 Design Reflections

We reflect from a designer perspective on synchronous feedback [14] and aesthetic choices among our etudes.

4.4.1 Grapher. The Grapher is a self-assessment tool and makes no explicit performance evaluation. This contrasts with Table of Time, which compares the user's input to a "ground truth" expected rhythm. Therefore, the Grapher is not designed with a specific *objective* in mind, but can support many possible objectives. The process of evaluating oneself and choosing an appropriate action is left to the user, hence our wording of "self-assessment".

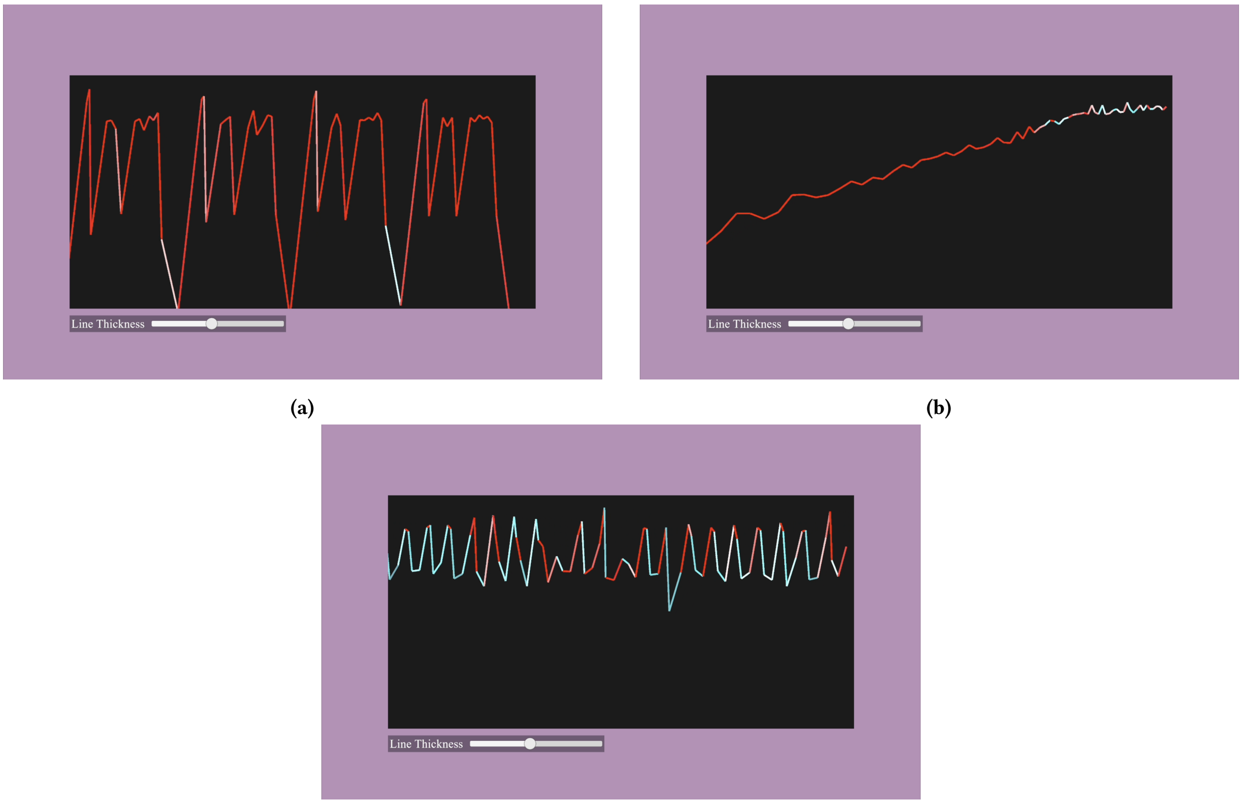
The etude uses data related to timing and velocity to create its visualization. The use of the color and horizontal position to represent velocity and timing respectively allows each variable to be legible independently.

4.4.2 Table of Time. Table of Time is the most "game-like" of our etudes, having the most explicit challenge to the player and overt evaluation of their performance. Echoing Ge Wang's assertion that the framing device of "expressive musical experiences as games" creates a "[l]ower inhibition for music-making," the aesthetic choices around this etude are important to creating a sense of context [21]. The game's sleek white-on-black color palette with bright, glowing objects suggests neon lighting. The "One, two, ready, go!" that opens the game mimics the start of Louie Zong's video *Rhythm Hell* [24], which itself parodies rhythm games.

The etude's *objective* is to perform the given rhythm as evenly as possible. Distinct colors make the central hexagon's position legible at a glance. An on-screen marker shows the player if they are ahead or behind the beat, represented by a vertical line. This marker provides an immediate *evaluation* and implicitly suggests the *action* required to achieve rhythmic consistency. The etude includes a metronome, which can be adjusted to different tempi and plays a sound when the number of subdivisions changes.

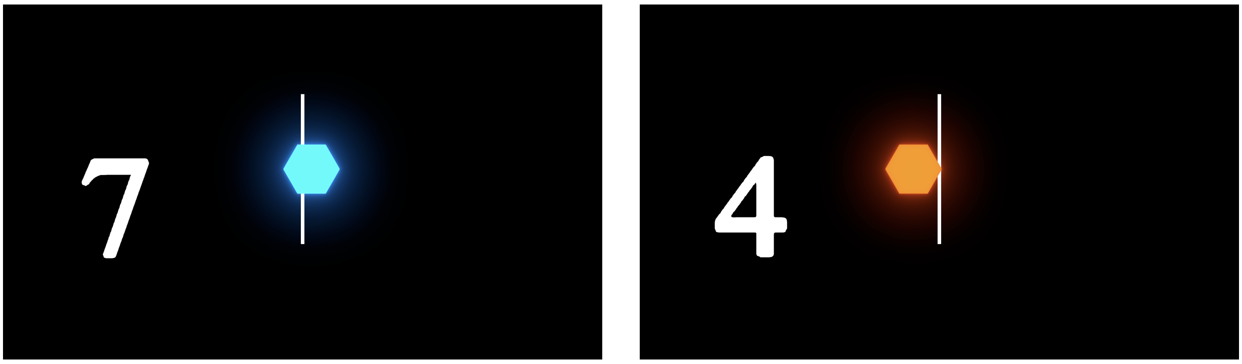
4.4.3 Popcorn. The Popcorn etude juxtaposes the "seriousness" of live performance with the silliness of bouncing popcorn visuals. It plays on the common joke that snare drum literature sounds like popcorn popping (see *Jazz Popcorn Robot* by Mortiz Simon Geist [15].) The bounciness of the popcorn also suggests

[1]In 2024, 47% of games released on the platform Steam used the Unity engine. In 2023, the number was 51%.
[2]https://www.rfc-editor.org/rfc/rfc768
[3]Unity does not allow auxiliary threads to call engine-related functions, so input messages need to be read through a buffer. Logging the time in ticks allows input timing to be independent from frame rate.



(a) (b) (c)

Figure 4: Screenshots from the Grapher etude. The position on the vertical axis indicates note density, while the color indicates velocity. (a) shows a repeated rhythm performed at a loud dynamic. (b) shows a player practicing an open roll from slow to fast. The color change shows the roll becoming quieter as the player speeds up. (c) shows a player performing a repeated rhythm while changing the accent to fall on different notes in the pattern. Inconsistencies in the shape of the graph show how shift in emphasis affects the player's timing.



(a) (b)

Figure 5: Screenshots from the Table of Time etude. The color and position of the hexagon indicate the player's rhythmic accuracy. (a) shows a player performing seven subdivisions to the beat with relatively high accuracy. (b) shows a player performing four subdivisions to the beat slightly early.

a bounciness to playing the instrument. In this way, the etude emphasizes an *objective* rather than providing an evaluation or suggesting changes in technique. The objective is also implied by the etude's use of information related to zone position and velocity, two factors that are key to sound quality and overall approach, while timing information remains conspicuously absent.

5 Case Studies

To explore VESPer's potentials and pitfalls from a user perspective, we present a qualitative case analysis of the first author's (A1) engagement with the etudes. A1 used VESPer during twelve 30-60 minute practice sessions in a month.

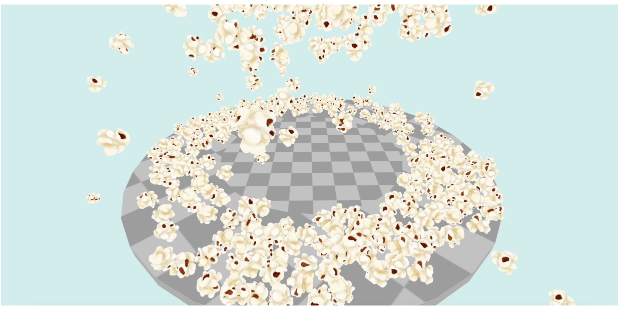


Figure 6: A screenshot from the Popcorn Visualizer etude.

Though the etudes were designed using a single snare drum, A1 was using a 4-piece drum kit with a hi-hat and two cymbals at the time. A1 placed a sensor on the snare but made use of the full kit when practicing. The etudes were running on a laptop behind and slightly above the hi-hat, roughly where a drummer might place a music stand.

This self-evaluation is non-exhaustive. A1's musical and design preferences are not generalizable to all percussionists; performers from different backgrounds, skill levels, and styles vary in how constructive the etudes are for their goals. A1's practice goals included:

- improving tuplet timing accuracy
- building ghost note and rim shot consistency
- displacing rhythms in odd meters

Given A1's role as VESPer's developer and etude designer, it is not surprising that the etudes already align with their practice goals. Our case studies provide insight into how real-time interfaces can integrate with a specific individual's process. We discuss future work with a broader range of use cases in section 7.

5.1 Case 1: A New Perspective

One of A1's earliest sessions with VESPer involved the juxtaposition of sixteenth notes and eighth note triplets. This pattern appears in contemporary classical music and approximates rhythms in Afro-Cuban and Brazilian music, where drum kit parts are often derived from rhythms originally played by separate people. A1 would play with one limb until comfortable, then add in the other limb, attempting to keep the rhythms consistent (see Figure 7).

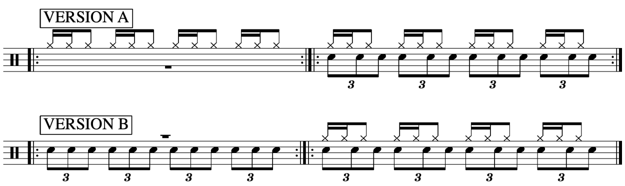


Figure 7: One of A1's exercises for practicing polyrhythms.

The sensor on the snare drum captured only one limb in this pattern. A1 visualized the timing using the Grapher. A1 found this approach comparable to playing the same exercise with one hand on the head and one on a rim or practice pad, using the difference in volume to isolate one side of the pattern.

A1 found the Grapher worked as expected, visualizing the literal time series of their playing (Figure 8). Visualizing the triplets was particularly readable, since evenly-spaced notes form a straight line on the graph. Any deviations were immediately noticeable, helping A1 adjust their timing. However, A1 noticed that they could often *see* changes in their playing before they could hear them, especially when first adding in a limb. VESPer's role as an outside perspective acts similarly to a teacher monitoring a student's playing, but provides feedback silently rather than vocally. In doing so, it offloads some effort for monitoring one's own playing.

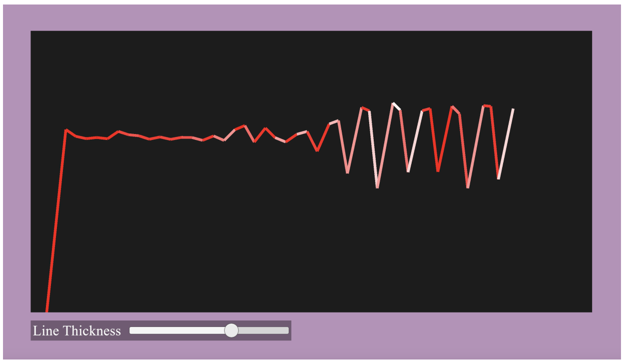


Figure 8: The Grapher rendering of A1's left hand when practicing Version B of the exercise in Figure 7. The relatively flat line (representing even note spacing) becomes jagged when the other hand is introduced.

5.2 Case 2: Unexpected Purpose

A1 was initially skeptical about the Popcorn etude's practical applications. They tried various exercises and songs with the etude running, but found little nuance beyond surface-level silliness. The "floatiness" of the physics reduced the response to changes in note velocity, which meant that the Popcorn did not have a clear readable output.

While practicing *Whisky and Mes* by the band Sungazer, A1 noticed that popcorn accumulated on different parts of the surface. This was due to the way the etude handled playing zones and the structure of the song. The A section of *Whisky and Mes* uses rim knocks on the snare, while the B section uses strokes in the center of the head. This caused popcorn to accumulate in the center zone during the A section, with a dramatic release on the first snare drum hit of the B section in a moment of catharsis. Since VESPer was initially designed using a single drum, A1 never anticipated this interaction, despite this being a common drum set orchestration technique.

This encouraged A1 to use the Popcorn etude with more groove-based music. When playing along to a Stevie Wonder song, they found they were instinctively playing rim shots on the backbeat and ghost notes in the drumhead center. This similarly corresponded to big bursts of popcorn along the edge and small bounces in the center. The visual made it easier to tell if the rim shot had been performed accurately or "missed," especially when playing with headphones. The zones on screen reflected the tactile relationship between A1 and their instrument. A1 had previously sought to improve their ghost notes, since they found their stick sometimes drifted off-center. With VESPer, they stumbled upon a feedback system through accidents and experimentation.

5.3 Case 3: Turning the Tables

A1 configured Table of Time between 50 and 60 BPM with subdivisions from 2 through 12. They typically practiced using single strokes on the snare, often keeping quarter notes on the hi-hat with their left foot.

A1 generally found the visuals to be unresponsive and unhelpful. At faster speeds, the indicator tended towards the center regardless of rhythmic accuracy, and at medium speeds, small playing inaccuracies translated to erratic movement that did not provide clear guidance. Increasingly, A1 realized they looked at the screen only when the subdivision changed and instead looked at their hands most of the time.

Eventually, A1 found Table of Time repetitive and so began experimenting with different stickings[4]. They experimented with double strokes and paraddidles (with accents), though found the latter challenging. A1 decided to stop using Table of Time so they could focus on combinations of subdivisions and stickings using an external metronome. At this point, they realized that the Grapher was ideal for visualizing even playing. A1 practiced with the Grapher and metronome until they felt comfortable with tuplet stickings, then returned to Table of Time with more confidence and capability. This mix of approaches demonstrates VESPer's role as an expansion to existing tools rather than as a replacement.

6 Discussion

6.1 Real-Time Interfaces and Pedagogy

Real-time visuals are valuable for working musicians because they can provide immediate feedback in pedagogy and practice. Game engines, which are designed for real-time input and visuals, are ideal for this application. In contrast to music teachers speaking with raised voices while students play, the use of visualizations allows performance and feedback to co-occur without interfering with each other. The ephemeral, time-based nature of sound can be given persistence, allowing information from a performance to stay on-screen. This is most evident in the Grapher, which dynamically shows a performance taking place over time on the horizontal axis.

Another advantage of real-time visuals is that users can self-assess or adjust without having to stop and manage recordings. This makes the Grapher convenient for practicing consistency across many short, repeated segments or visualizing continuity across a point of change, like A1's exercises from subsection 5.1.

While sensor data lays the groundwork for VESPer and its etudes, it does not guarantee their success. Students learn in different ways and a purely numeric evaluation of playing is not sufficient alone to be "teaching." Moreover, self-recording remains important for demonstrating longitudinal progress. Instead, real-time interfaces expand an ecosystem of tools and techniques for musicians' learning. Next, we provide guidance for designing such interfaces.

6.2 Visualization for Real-Time Feedback

Sound visualization already plays an important role in contemporary music and NIME research. However, not all visualizations provide real-time feedback. For instance, Sa's fungible cause-effect mapping [16] applies to live performance visuals, but is less applicable for pedagogy. Ideally, interfaces that use percussive controllers as input devices should (1) *convey relevant information* and (2) be *readable at a glance.*

[4]This practice of adding variations to existing exercises is common among percussionists.

6.2.1 What is relevant? When practicing, not all information is relevant to a particular practice goal. This is true both with and without technological assistance. For example, a performer may prioritize accuracy over tempo when rehearsing a difficult passage. Similarly, when designing a practice etude, not all sensor data is useful. An etude about precise rhythms (e.g. Table of Time) might not use EHSP's velocity or "timbre" parameters, whereas an etude about fast, quiet zone changes might make heavy use of both.

Curation of relevant information is also reflected within EHSP itself, where the Sensory Percussion 2 software converts sensor inputs to OSC messages, which are in turn sent to Unity. Each etude filters different MIDI note numbers from the OSC data, ignoring or combining values as the specific scenario demands. For instance, the Grapher etude treats the center and edge zones differently, while the other two etudes treat all notes with a "play" message identically.

This curation process can center a technique of interest, but it can also perpetuate implicit standards and expectations. For example, Table of Time evaluates tuplet timing according to a rigid mathematical division of the beat. Once could imagine how this might translate well to corps-style marching drummers or New Complexity performers. However, in many contexts, such as certain styles of chamber music, this may not reflect expectations for interpretation.

6.2.2 What is legible? For information to be useful in real-time etudes, it must be easy to read quickly. A raw text output of the data sent from a drum trigger is comprehensive, but is likely more difficult for a human to parse than a graphical display.

There are many ways to present feedback. Lisa Martin offers two examples relevant to our legibility design goal: *directive feedback*, which explicitly details an adjustment and often directly suggests a corrective action, and *facilitative feedback*, which guides students while still allowing them to make their own choices [14]. Examining the etudes above, we see that Table of Time is an example of directive feedback. The moving icon shows where the performer sits relative to the expected note position, inviting them to adjust accordingly. The Grapher on the other hand provides facilitative feedback because its "commentary" allows players to exercise their own judgment about their playing.

Even if the feedback purpose is clear, this does not guarantee legibility. In the second case study, A1 found that "floaty" physics limited the Popcorn etude's practical utility when drilling fast dynamic changes. Similarly, in the third case study, the lack of a clear, immediate response when playing at higher densities resulted in a less constructive experience. Additionally, aesthetic choices impact legibility. Flashing lights can be distracting and overstimulating, even if they are highly responsive, while static readouts can be functional but uninteresting. As such, future designers must put these design choices and tradeoffs in conversation with particular practice goals.

7 Conclusion and Future Work

We present VESPer, an open-source library for integrating EVANS Hybrid Sensory Percussion and Unity, along with three etudes showcasing its potential as a practice aid, pedagogical game, and joyful catalyst. Building on our design reflections and practice case studies, we discuss *relevancy* and *legibility* as important factors for synchronous formative feedback interfaces.

We see opportunities to continue evaluating VESPer's constructive value across contexts. The first author's case studies (section 5) are non-exhaustive evidence for VESPer in a longitudinal, real-life practice setting. Percussionists from different genres and experience levels will likely have different experiences with this toolkit. Future studies could engage with how new learners interact with VESPer, how educators might incorporate real-time interfaces into their lessons, or the different experiences between Classical and Jazz percussionists. Additionally, measuring the extent to which synchronized visuals affect a performer's sense of rhythm quantitatively could provide insight for designers and educators.

Regarding VESPer as an open-source library, we pave the way for developing more robust musical interfaces and games using EHSP. Future development work includes more specific parsing for OSC messages, such as MIDI CC messages, and making the interface compatible with other hybrid percussion. EHSP can also receive MIDI information from other devices, including virtual ones, which would allow Unity to influence sound selection in EHSP during a performance. We also hope to use EHSP's unique features to create more etudes, such as games about smooth zone changes or fast transitions between techniques.

8 Ethical Standards

This research was financed through the second author's start-up fund. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. No human subjects outside of the authorship team were involved in this research.

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A Video Examples

Demonstrations of the etudes described above may be found here:
https://www.youtube.com/watch?v=OXlaIJBN1iE

B Code Repository

The demos and starter code related to this paper can be downloaded here:
https://github.com/the-bard-in-the-lab/ehsp-interface-demos