

# MUSIC TECHNOLOGY'S INFLUENCE ON FLUTE PEDAGOGY: A SURVEY OF THEIR INTERSECTION

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## ABSTRACT

Technology improvements trigger innovations in modern culture, and these concepts evolve into more advanced versions of the original. This deepens our understanding and strengthens bonds connecting past and future. Advances in technology-integrated musical instruments date to the early 20th Century, where the scope of our research in augmented flutes and flute-like controllers begins. We explore the *flutist's practice room* by examining its past through a historical literature review. We then investigate how advances in technology impact flute pedagogy. We seek to understand flute designs and the evolution of pedagogical techniques, while proposing a way to fill in the gaps in this research field.

## 1. INTRODUCTION

Progress in digital signal processing (DSP) techniques gives us substantial control over technology. Low-cost easy-to-use sensors and microprocessors provide real-time interaction and high information rates. These technologies can enrich and perfect an artist's performance.

Prior implementations of technology-enhanced wind instruments have enhanced performance, or provided details about a performance characteristic, such as the air jet expelled during flute playing. Few technologies have been used to assist during practice sessions, or to provide musicians with feedback, or to assess pedagogical techniques. We touch on the more prominent discussions about flute, technology, and practice and performance techniques to indicate areas that lack information or development. We begin by examining the pertinent history of flutes as they apply to post-modern flute pedagogy. Then we look at how technological developments have been applied to modernize the *practice room*.

### 1.1 Flute

The flute dates back to the Palaeolithic Age. They have been constructed from bone, mammoth tusks, bamboo, wood, crystal, glass, porcelain, ivory, plastic, and metals (such as tin, nickel, copper, silver, gold, and platinum). There has been a wide range of tone-hole and key designs. The quantity of tone-holes and their placement shifted since early caveman days. [1]

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Over the years, technological developments have steadily improved the tonal range and sound of the flute. Hotteterre (1680 - 1761) developed an early rendition of the modern flute. He lengthened the instrument and added a D# key. Nicholson (1795-1837) crafted larger holes for both the fingers and the mouthpiece. In 1849, Boehm (1794-1881) reworked the flute body and introduced an updated key design. This allowed the development of a fingering system still in use today. Diverse *minor* improvements (corrections based on measured tube acoustical properties and modifications in key placement and in overall design) endure to the present day. No *major* changes in flute design have occurred since the mid-19th Century. Consequently, development of flute pedagogy has also halted. [1][2]

The flute's monophonic sinusoidal-like waveform and open tube acoustics make it a natural candidate for DSP (such as pitch extraction), which can be used for MIDI encoding without the issues associated with polyphonic instruments. Flute construction allows for sensor integration to assess multiple facets of performance. In Section 2 we discuss how *flute technology* researchers use this design scheme.

## 2. HYPERINSTRUMENTS: CONTROLLERS, AND INTERFACES

A hyperinstrument is "a musical instrument designed or adapted to be used with electronic sensors whose output controls the computerized generation or transformation of the sound." [3][5] Technology enhances and extends an instrument. Integrating technology with musical instruments, along with the rapid development of ubiquitous technologies, led to dramatically improved interactions between the artist and instrument in the 1980's. [2][6]

Hyperinstruments<sup>1</sup> create capabilities for artists to extend past the scope of traditional instruments. Music researchers continue to explore and develop hyper-flutes. Herein, these are either traditional acoustic flutes augmented with sensors and processors, or flute-like controllers with embedded sensors and processors, each driven via computer.

Hyper-flutes provide parameters through which a composer or performer transforms the characteristics of sound. This often requires a modified or completely new playing technique. For instance, researchers have aug-

<sup>1</sup> e.g. Tod Machover [3][5] [7], Ajay Kapur [8][11], Diana Young [12], Jordan Hochenbaum [13][14], etc.

mented flutes with sensors and controllers to follow scores or to control a synthesis engine. Interaction between artist and instrument becomes more intricate and grants a deeper understanding of and connection between action and sonic outcome. [7]

In addition to hyperinstruments and controllers, researchers are developing musical robots in order to bridge the gap between human and technology [10-11, 15-27]. Musical robots are designed to emulate human behavior and interaction during a performance. This demonstrates a deeper understanding of the relationship between the embodiment and human action to become stronger. A robot playing a musical instrument in the style of a human gives us better comprehension of the human body and its movements.

Section 2.3 goes into detail about robots that play the flute. It explores the long-term iterative process carried out by researchers at Waseda and Kyoto University.

## 2.1 Augmented Flutes

An early sensor-augmented flute is the *MIDI flute* developed at IRCAM. In 1982, Vercoe and flutist Beauregard connected the flute to DiGiugno's 4X audio processor, which provided real-time pitch tracking using DSP. Bucoureau, Starkier, and Beauregard then created the final version, which was used as a score-following system in several music compositions. DSP extracted from sensors on the flute provided real-time data to drive MIDI information. They focused on controlling a synthesizer by digitizing natural acoustic flute gestures [1, 6, 28-33].

Ystad and Voinier's *virtually real flute* incorporated sensors that controlled synthesis models to assist the flutist in learning new playing techniques. The research discusses sensor technology and data processing algorithms for driving a synthesis model. They focused on refining a *hybrid model*, combining signal model and physical model to get a stable controller. With interactive technology activated by foot pedals, this augmented flute could be used as a traditional flute devoid of obtrusive electronics. "The goal in designing this interface was to give flautists access to the world of digital sounds without obliging them to change their traditional playing techniques." [34]

Palacio-Quintin's *Hyper-Flute* uses embedded sensors, where an acoustic flute interacts with live signal processing. The computer is a virtual extension of the flute, adding self-accompaniment. This creates a real-time interactive composition model, where the artist is part composer, part performer, and part improviser. Different playing techniques are required to interact with the sensors. The ability to control the live signal processing adds additional complexity. [35]

Da Silva *et al.*'s *On the Use of Flute Air Jet as a Musical Control Variable* focuses on using the air jet (velocity and direction) expelled from the embouchure to drive digital audio effects. [36][37] The technology implements a virtual extension to the flute. Refined, advanced sensing technology and high frame rate processing minimize distracting delays and provide interesting interaction.

Erskine's *E-suling*, an augmented Indonesian *suling* (flute), is a more recent iteration, and another facet, to promote a hyperextension of music performance. "This

custom electronic flute is an attempt to extend the traditional techniques of the instrument into the realms of live audio capture and/or effects processing for the accomplished player looking to experiment." [8] A modified *suling* has been used in composition and for performance.

## 2.2 Flute-like Controllers

Yunik's *microprocessor-based flute* and *digital flute* are two important flute-like controllers, dating back to mid-1980. These are the basis for the Ocarina [38], with a microphone input controlling amplitude and buttons (or virtual multi-touch buttons) to control pitch. The concept provides a straightforward learning device, or teaching tool, that does not require the ability to read music. A simplified fingering arrangement allowed for easy use during real-time performance. These early iterations focused on the novel use of technology and unique implementation approaches. Technology limitations of the time made it a challenge to actualize these systems. [39][40]

The meta-wind instrument physical model *Whirlwind* developed by Cook encompasses paradigms of most wind instruments, allowing it to emulate a flute, recorder, clarinet, saxophone, trumpet, trombone, or hybrids of these acoustic instruments, all made possible through physical modelling. This algorithm is a synthesis model that provides valuable insight about the acoustics of musical instruments. Along with the synthesized physical model, a meta-wind instrument controller (*HIRN*) worked with and controlled the synthesis algorithm. This meta-controller (shaped and designed like a flute) creates the opportunity for real-time performance control. [41]

Fels and Vogt's *Tooka* by explores the interaction between two persons jointly performing on the same flute-like controller. *Tooka* explores the product of non-verbal communication between two performers who must cooperate to achieve a successful performance. The ultimate goal is "to create new musical controllers that tap into the intimacy between two people to create new forms of expression through sound." [42] This kind of interaction is difficult to reproduce on traditional acoustic instruments.<sup>2</sup>

Scavone's *The PIPE* contributed to the research in static flow breath pressure as a control input. "Traditional wind instruments are driven by dynamic air flow through an acoustic air column." [43] Development spanned several years, with the completion spurred by enthusiasm to control real-time physical modelling algorithms for music compositions. It is a compact design for flute-like controllers, meant to emulate a recorder and to easily integrate with existing woodwind tone-hole synthesis models. It uniquely includes a removable contoured mouthpiece, minimizing unhygienic circumstances. [37][43]

Cannon *et al.*'s *EpipE* is a flute-like controller created to research expressive music techniques with respect to tone-holes. *EpipE* mimics the design and interaction of the Irish Uilleann pipes and allows in-depth research for tone-hole sensors. The iterations of the *EpipE* realized a new tone-hole state-sensing solution. [44][45]

Another research topic determines "the usefulness of vibration to a wind performer."<sup>3</sup> Birnbaum's *BreakFlute*

<sup>2</sup> [www.youtube.com/watch?v=2WHu0UJcb9A](http://www.youtube.com/watch?v=2WHu0UJcb9A)

<sup>3</sup> [www.idmil.org/projects/breakflute](http://www.idmil.org/projects/breakflute)

and its predecessor the *TouchFlute* are meant to illustrate the integration of vibration actuators inside the mouth-piece and tone-holes. The *TouchFlute* affords arbitrary control over the parameters of the actuators, creating the ability to impose itself as congruent or disparate haptic feedback for the performer. The research focuses on “whether musicians derive useful information about their performance from instrument vibrations and how to incorporate vibrations into gestural interfaces.” [29] Initial studies indicate traditional wind players prefer haptic feedback in wind controllers. However, the devices are “not suitable for rigorous musical training and performance” due to the need for a refined breath sensing technique and an integrated wireless system. This is an opportunity for further research. [29][46]

The research by Romero *et al.* concerns a *Virtual Flute*, where a flute-like device adorned with sensors tracks a musician’s breath pressure and finger movement, giving feedback about performance technique. This is a teaching tool, rather than a performance tool (unlike many devices cited herein). Researchers measured the breath pressure of several flute players to determine an optimal operational range and to detect note onset. They focused on methodology and constructivist pedagogy, but did not document the design and implementation of the gesture tracking and signal processing techniques. The flutist interacts with a computer, which acts like a teacher and gives feedback on performance technique by analysing via a “call-and-response technique”. The computer dictates what is to be played, then assesses performance. It “provides the necessary information to the student to learn how to play the basic notes on a flute and gives the opportunity to practice and be evaluated.” [47] Despite sparse documentation for this prototype device and trial software, the paradigm of technology-enhanced lessons shows potential. [47][48]

Commercial devices akin to the flute-like controllers discussed above are part of the Yamaha WX series (WX11, WX7, and WX5). The WX11 and WX7 were designed to provide expressive control to MIDI note information. “The Yamaha WX series allows a wind player access to a wide variety of synthesizer sounds through the expressiveness of a wind instrument.”<sup>4</sup> One could easily add sensors to augment the degree of musical expression. The WX series improved as technology advanced. The WX5, the most recent edition, is touted as “a MIDI controller for '90s wind players.”<sup>5</sup> The iterative design process in commercial devices show what technologies prove most valuable and most profitable.

### 2.3 Robotic Interfaces

“The research on musical robots opens the opportunity to study several aspects of humans; such as understanding the human motor control, understanding how humans communicate ideas, finding new ways of musical expression, etc. As a result, the research on musical robots has been attracting the interest of researchers from different fields such as: robotics, computer science, art, entertainment, etc.” [22] The “Humanoid Project”, for anthropo-

morphic robots to co-exist and interact with humans, began in 1992 at Waseda University in Japan, with the goal to provide supplementary information to beginner musicians during instruction. The project includes robots for many instruments, but we focus on flute playing robots. WF1, their first flute-playing robot (1990) encouraged better communication between humans and robots. Waseda researchers theorized that building robotic components to mimic human movement would provide an accessible interaction and relationship between humans and robots. Since 1990 they have developed flute-playing robots with steadily improving human-like characteristics. Solis *et al.* posit that an “anthropomorphic robot that is not only capable of playing the flute as human does, but it is able also to help beginner students to improve the sound quality of their performances by the demonstration ... the robot can provide graphical and verbal feedback to correct their executions.” [19][20] Waseda research enables robots to analyse a musical performance and give feedback. [19][20][26]

The robot emulates each human organ necessary in playing flute: respiratory system, fingers, mouth, throat, tongue, neck, etc. These parts then recreate the flute-playing paradigms by affording capabilities and techniques, such as vibrato, double tonguing, attitude control, trilling notes, etc. Beginning in 2003, developments to improve both the mechanical design (technology) of the robot and the expressivity (human-component) of its performance capability evolved to the WF-4 series. These musical robots not only perform as flute players, but also act as a teacher’s aide during flute instruction. The robot and the teacher ‘work together’ to assess and provide feedback to the student during a lesson. [19][20][26][49]

Chida *et al.* discuss the mechanical parts, their construction, purpose, and contribution to the overall design. The paper includes results of sound quality evaluation (using real-time FFT analysis), comparing the previous version of the robot (WF-3), the recent version (WF-4), and a human, each playing a flute. These analyses provide insight into acquiring an acceptable performance quality of a flute-playing robot, as well as an interesting spectrum analysis of any given note (whether human or robot produced). Chida *et al.* determined that higher standards of mechanics and parts result in more true-to-human performance quality. [49]

In 2007, Solis *et al.* studied vibrato to improve its production by updating the mechanics of the robot’s vocal chords and lungs with WF-4RIII and upgraded the design of the lips, oral cavity, and tongue in order to clarify the sound and better define the articulation between notes with WF-4RIV. They discovered that the majority of vibrato emanates from the throat and diaphragm, which prompted upgrades for the lungs and throat. WF-4RIV replicates human lips, neck, arms, fingers, tonguing, vocal cord, lungs, nose, and eyes. They refined the purpose of musical robots to be a “better understanding about how humans are [capable] of synchronizing multi-degrees of freedom.” [21] They state that this “approach may not only be useful in studying human motor control, but also may open the possibility of preserving live performance of [virtuoso] players as a form of entertainment.” [21] Researchers performed signal processing analysis and

<sup>4</sup> windsynth.net/basics.html

<sup>5</sup> ibid.

subjective analysis from flute students on the WF-4RIV, the WF-4RIII, and a professional flute player. WF-4RIV came closest to the professional flute player's performance. [21][22][23]

The following year, Solis *et al.* added a General Transfer Skills System (GTSS) to improve the WF-4RIV's cognitive and perceptual abilities. This system has real-time capabilities and includes an offline database of stored knowledge from previous interactions. This complex system employs several sub-systems, including sensory, recognition, evaluation, and interaction systems for the real-time component. The systems use both an audio and a video input, and human skill model and task-dependant evaluation, which used a HMM for the offline component. Solis *et al.* also established a auditory feedback components to the robot's design, including "Expressive Music Generator (ExMG), Feed Forward Air Pressure Control System (FFAiPC) and Pitch Evaluation System (PiES)" by using neural networks. [23][24] The ExMG is "designed to output musical information required to produce an expressive performance." [24][25] This version of the robot includes a self-assessment component where the robot can evaluate its own performance using pitch detection to determine sound quality via several signal processing techniques, including "time-domain analysis, autocorrelation, adaptive filter, frequency area, [and] modelling human auditory system (neural networks)." [23][26] Each component underwent several experiments, but ultimately enhanced the learning experience of the student.

Beginning in 2009, Waseda researchers proposed "a Musical-based Interaction System (MbIS) ... to enable the robot to process both visual and aural cues coming through the interaction with musicians." [18][26] This called for a more advanced visual tracking component, "so that the robot can process motion gestures performed by the musical partner in real-time which then directly mapped into musical parameters of the robot's performance (i.e. vibrato, sound volume, etc.)." [18] Eyes and ears (cameras and microphones) were integrated in to the robot to facilitate visual recognition (facial, instrumental, gestural, etc.) through motion tracking and a binaural acoustic component. By 2010, Waseda researchers integrated two human-machine interaction levels: a beginner level with simple controls and communication and an advanced level with a more complex interface and interaction scheme. The beginner level utilizes motion tracking and average peak detection tempo analysis, and the advanced level incorporates particle tracking and Bayesian filter-based pitch recognition. The advanced level can perform on stage in front of an audience. Musicians tested each level of interaction, and experiments showed promising results for effective musical performance control. Both interaction levels facilitate the potential for a flutist of any level to enjoy an enriching experience performing with the robot. [18][25]

Researchers at Kyoto University also contributed towards the development of intelligent musical robots. Lim *et al.* illustrate a method for integrating audio and visual cues for real-time synchronization between human flutist and robot flutist using score-following techniques. They determine beat tracking via a visual beat cue paradigm

and acoustic note onset detection. This integrated multi-modal tracking technique gives better results than with either technique alone. Natural movements of the flutist and of the instrument itself can be capitalized on for extracting temporal information as the flutist moves while performing the music. Signal processing techniques applied to visual and auditory information gave promising preliminary results. "By watching and listening [to] a human perform, a robot musician may learn how to make gestures that correspond musically with the music it plays. Or, it may learn how to play music expressively not only by mimicking a human's pitches and rhythms, but also minute volume and tempo variations." [16]

An interactive human-robot performance ensemble is one of the more recent contributions of Kyoto researchers. They merge (1) a Theremin-playing robot, (2) gesture recognition (via human flutist), and (3) beat tracking (via human percussionist), to achieve rhythm, melody, and harmonic synchronization. "The robot recognizes visual cues through finite-state-machine based gesture recognition and auditory cues through real-time beat-tracking." [17] Others, like Solis *et al.*, have created solo musical instrument playing robots, so Mizumoto *et al.* focus on robot ensembles and interactions amongst robots and human performers. This is similar to developments by Kapur *et al.* at California Institute of the Arts, with their Karmetik machine orchestra. [8][15]

Two kinds of skills must be mastered for a successful human-robot collaborative performance: performing skill and interaction skill. The latter includes recognition and synchronization methods. The research by Mizumoto *et al.* shows promising results for rhythm synchronization, but needs further work in melody synchronization. [17]

### 3. PRACTICE SPACE

Hyperinstrument practice space differs from that of a traditional acoustic musical instrument. A classical musician interprets and performs a piece of music. But with an electroacoustic musician, there is less definition between performer and composer. "Mixed virtual and real elements create a powerful performative situation." [2] Performing with integrated electronics is a more interactive and embodied experience. "Extended techniques demand many new fingerings and a diverse set of breath, hand, and tongue actions." [50] Chadabe, an early researcher for real-time computer music systems, coined the term *interactive composing*, and discusses this relationship and intersection between performer, composer, and improviser. [51] "Sound manipulation technologies in extant flute works include amplification, delay, filters, panning, reverb, multi tracking and DSP." [50]

#### 3.1 Early Compositions

Compositions created during the emergence of electroacoustic music attracted the use of technology in music performance. In 1949, Schaeffer composed one of the first music concrete pieces, using flute and recordings, called *Variations sur une Flute Mexicaine*. Schaeffer created variations of acoustic flute by playing recordings at different speeds. In 1952, Maderna composed the first

piece using the flute as an acoustic instrument along with electronic tape sounds in *Musica su Due Dimensioni for flute, percussion, and electronic tape sounds*. Two notable pieces for flute and electronics are Luening's *Fantasy in Space* and *Low Speed*. Each manipulated the sound of the flute through processing. In the 1990's, Eustache, helped develop an interactive computer system, *Automated Harmonization of Melody in Real-Time*, which provided one of the first real-time melodic analysis and harmonic accompaniment during a performance. [28][50][52]

### 3.2 Extended Techniques

Palacio-Quintin's *Hyper-Flute* is one of the more developed and longer assessed devices described herein. She built this augmented flute in 1999 for controlling DSP effects on the flute's natural sound, to compose unusual electroacoustic soundscapes. She continued studies as a doctoral student in 2007 to expand the hyperinstrument repertoire, to develop purposeful mapping strategies, to update the *Hyper-Flute* design, and to build a hyper-bass flute. As a virtual extension of the flute, the computer environment is limited by its programming and parameters. Playing an extended instrument requires a new way of performing, as other researchers discovered when building and performing with these instruments. The interaction between acoustic playing techniques and the motion captured by the sensors is intimately connected. Musical gestures are a part of the whole. The resulting musical structures in electroacoustic music can affect both the macro-structure and the microstructure of a piece. These structures have different levels of interactivity, including the original flute sound, the processed flute sound, and additional effects independent of the flute. Practice is therefore focused on integrating all gestures in to the performance in order to mediate between all of the structures. This includes refining the DSP and mapping strategies. Learning a new electroacoustic instrument and its extended techniques is equivalent to learning a traditional acoustic instrument. It has taken her 8 years to master the *Hyper-Flute* and be able to have fine-tuned gestural control over the DSP effects. [53][54]

Penny's *The Extended Flutist* draws out a key point missing in much of the literature: evaluation through reflection. Comprehensive reflection before, during, and after a performance is crucial towards disseminating information gathered through the creative process and towards improving all aspects of the performance. Her thesis focuses on practice-based approach to research through performance and provides a framework for auto-ethnographic assessment of flute pedagogy. It addresses many of the past technologies and compositions leading up to and informing the design for her own system.

*"Gestural elements of performance have been a significant part of interactive music research, in physical and electronic forms. ... These gestures become part of the new performance image ..., and contribute new elements to the projection of musical ideas and communication. Exploring the impact of technology on the flute player implies significant research of the nature and context of new music practice and the experience of performance. Employing a variety of representations to explore flute*

*and electronics performance practice, layers of investigation have been constructed to encompass a broad contextualization of historical shifts across the last half century, to illustrate personal encounters with technologies and new techniques, and to capture the experience of performance through presentation, reflexivity, and analysis. ... The flautist's relationship to the electronic device includes interconnections of physical activation, understanding of digital processes and illusory sensations. ... The important element in this discussion is ... how the translation of digital data to sound intersects with the flautist and provokes adjustments in mental and bodily responses. The tensions that arise, the confrontations of dealing with imperfect machinery, the time commitment demands and the uncompromising nature of both human and inhuman behaviours all stretch the performer to new levels of experience, despair and resolve."* [50]

These are the kinds of realizations, assessments, and thorough investigations necessary in our research field!

## 4. PERFORMANCE SPACE

An early "new interface for music expression"<sup>6</sup> is Mathews' *Radio Baton*. This interface had many years of refinement and has provided a basis for similar interfaces. It borrows from well-established musical paradigms, as both a conductor's baton and as a drum mallet, creating an easy-to-grasp performance space. The interface demonstrates the need for adaptable and ubiquitous music technologies that maintain an expressive requirement. The instrument may be easily understood, but a degree of finesse and practice is needed to perform with minute gestural information. The design is simple to reproduce or to give to someone else to play. Generalizable is an important feature missing from many devices. [55]

The multimodal music stand (MMMS), developed by Bell *et al.* in 2007, captures expressive performance gestures to control interactive music. New musical instruments should be accessible, offer expert control, and develop a repertoire. This device creates an environment to have the same rich interactive music compositions without the need for an electronics-tethered instrument. "It augments the performance space, rather than the instrument itself, allowing touch-free sensing and the ability to capture the expressive bodily movements of the performer." [56] This device is a controller, but it interacts with any instrument or musician. The MMMS presents the artist with an expressive gestural interface. This system does not require playing techniques outside of traditional instrument pedagogy; however, it does rely on ancillary performance gestures to inform the interactive music system. The motion of a flutist using this device is captured via blob tracking of the flute angle and eye tracking captured the flutist's head movement. Developed as both a musical device and a research platform, MMMS promotes increased expressivity without hindering performers. The MMMS encourages generalizable research in interactive composition within the performance space without the need to master control of the integrated electronics of a hyperinstrument. [56]

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<sup>6</sup> nime.org

Not far from the MMMS research is the *sonified music stand* built by Grosshauser & Hermann in 2009. The prototype, along with its demonstrative applications, facilitates musicians during music training with real-time feedback. The *sonified music stand* evaluates a musician's motor activity during a performance and displays real-time activity features as sonic feedback. The device employs a combination of sensor technologies, suitable feature extraction determined through data mining, and engaging sonification design. Grosshauser & Hermann provide a physical and programmatic problem, the pedagogical relationship and how it was solved, and the result. The information gathered in these cases influenced the design of the device. Dividing the problem space into workable solutions provides a unique perspective concerning the iterative design process. Even as a prototype design, the first impressions of using the device are deemed promising. A violinist could intuitively comprehend how to properly bow a violin and, through sonic feedback, learn how to optimize movement. [57]

*Shaken or Stirred ...* is an ethnographic review of multiple flutists' performances of *NoaNoa*, a piece for flute and electronics. *NoaNoa* includes an amplified live flutist, pre-recorded flutists, and real-time electronics. Natural and synthetic reverberation effects play a major role, as does the interaction between live and pre-recorded flutist. "The hybridity of the live flautist and the electronic component produces the flute sounds in the realm where the dichotomies between self/other, active/passive, maker/made, whole/partial and woman/man are continuously ambiguous." [58] The research gives insight in to interaction between flutist and electronics during a performance and assesses the interaction with pre-recorded flutists and collaboration with the sound engineer. It harmonizes with Penny's research on the relationships and inter-relationships between performer and technology.

Penny discusses how the sonic and performance environment is enriched by technology through electroacoustic music. Work discussed in Section 2 echoes the belief that, with the integration of technology in performance, "the traditional idea of the flautist has transformed into a meta-instrument entity: a collaborative symbiosis of instrumentalist, technologist, hardware, software, virtual and real performance space, and sound." [2] *Flutes, Voices, and Maskenfreiheit* investigates various layers within a performance space. Penny remarks that the "emergent performance ontologies of the electroacoustic instrumentalist introduce a plurality of performative layers, evolving into a complex, yet compelling exploration." [59] The musician, technology, music, and the performance are bound tightly together. She discusses three compositions for flute, other voices, and electronics and how to mediate a performance with disembodied music (like amplified flute emanating from speakers). The controlled chaos of the electronics adds complexity. It is the musician's job to maintain control of all aspects of the performance while still conveying the emotions and message of the composer. This is "a performative journal responding to the sensations of the amplified flautist's experience and performance presence," [59] describing the personal accounts a flutist performing each of these electroacoustic pieces. It is an attempt to delve "into the musical mean-

ings and performative understandings of extended performance ontologies." [59]

## 5. SUMMARY

New technologies and innovative tools impact the development of human culture. Although several iterations of these flute technologies have been developed and used, significant gaps remain in the research. Few of them have received rigorous long-term usability testing or have provided evidence of use by multiple musicians. Building an interactive MetaFlute<sup>7</sup>, receiving data from its sensors, and processing that data, could feasibly contribute towards pedagogical improvement. Few researchers continued to either iterate on this scheme or expand the research field. This leaves ample opportunity for a realized system with a more significant scope, breadth, and depth in research. There is limited documentation about using these flute technologies in the practice space versus the performance space, although most research supports the necessity for extended playing techniques to perform with an augmented flute or flute-like controller. Many of the articles do not justify why technologies are used, however the *BreakFlute* thesis did detail the need for a wireless system. So far, musical robots seem to be the ideal pieces of technology to provide the informative data from human-technology interactions. But with our modern technology, can we adapt this provision for, let's say, a mobile device in a practice room?

Expressive music instrument controllers and interfaces provide users at all levels with the opportunity to emulate the responsiveness and feel of traditional musical instruments. This new device (often used in real-time performance) is potentially an accessible music-learning tool. The instruments and interfaces have been built as a proof of concept, often with no real measured data. This opens the door for further research. The distribution capabilities and reliability testing should be addressed: so questions like "Is this repeatable?" "Can this be learned?" and "How ubiquitous are these augmentations?" should be addressed!

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<sup>7</sup> <http://metaflute.us>

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