The Musical Fireflies - Learning About Mathematical Patterns in Music Through Expression and Play

Gili Weinberg
MIT Media Laboratory
20 Ames St., E15-491
Cambridge, MA 02139 USA
gili@media.mit.edu

Tamara M. Lackner
MIT Media Laboratory
20 Ames St., E15-020b
Cambridge, MA 02139 USA
tlackner@media.mit.edu

Jason Jay
Knowledge Learning Corp.
4340 Redwood Hwy., Bldg. B
San Rafael, CA 94903 USA
jason.jay@post.harvard.edu

Abstract

The Musical Fireflies are palm sized digital musical instruments that introduce mathematical concepts in music such as beat, rhythm and polyrythm without requiring users to have any prior knowledge of music theory or instruction. Through simple controllers, the Fireflies allow users to input rhythmic patterns, embellish them in real-time by adding rhythmic layers, synchronize patterns, and trade instrument sounds. Since interaction with other players increases the richness and complexity of the experience, the Musical Fireflies also motivate collaboration and social play.

1 Introduction

Traditional tools and methods for learning rhythm, as well as other musical concepts, usually separate the figural, intuitive experience from the formal, analytical internalization of the material [1]. When learning to play musical instruments in the formal mode, certain important musical aspects, which came naturally in the figural mode, may be temporarily hidden when students try to superimpose analytical knowledge upon felt intuitions. If this phenomenon is not acknowledged by a teacher or mentor and the gap between the different modes is not negotiated, it might ultimately lead students to cease altogether their participation in musical life [2].

This paper presents an interactive musical network of palm sized digital musical instrument called "Musical Fireflies," which are designed to help bridge the gap between the figural and formal modes. By employing digital interaction and wireless communication, the Fireflies provide players with expressive and fun rhythmical experiences that can be easily transformed into an analytical and formal exploration. Through simple controllers, the Fireflies allow players to input rhythmic patterns, embellish the patterns in real-time, synchronize patterns among different players, and trade instrument sounds. For a single player the instrument can provide figural as well as formal familiarization with musical concepts such as accents, beats, rhythmic patterns and timbre. During the multi-player interaction a wireless network is formed, which can provide novices, as well as professional musicians with an interactive group experience that leads to a deeper internalization of advanced musical concepts such as the correlation between monorhythmic and polyrhythmic structures.

1.1 Digital Manipulatives

The development of the Musical Fireflies is informed by the notion that interaction with digital physical objects, also known as digital manipulatives, can enhance learning [3, 4, 5]. The Musical Fireflies extend these studies to a musical realm by providing an expressive experience that can draw players into a meaningful musical exploration without requiring an exhaustive learning process, virtuosi performance skills, or an extensive knowledge of music theory [6, 7]. Access to and manipulation of Logo code for customizing the Fireflies also provides a basic and friendly introduction to Midi programming and electronic sound. Advanced players can therefore deepen their learning experience by reprogramming the Fireflies and adjusting their functionality to match personal musical interests and abilities.

1.2 Group Playing

The Fireflies are designed to provide simple and immediate musical interaction for single players at preliminary stages, which leads to richer, more complex musical experiences when multiple players, using multiple instruments, interact with each other. The instruments' wireless communication system allows players to explore new interactions by communicating and sharing their music with others. Through infrared communication, players can synchronize their instruments with other Fireflies, which are programmed in the same manner by other participants, and enhance their simple, monorhythmic patterns into a polyrhythmic experience. It is in these synchronized social interactions that the further mathematical aspects of the toy arise where individual users can obtain an understanding of their rhythmic patterns in relation to the group's composition [8]. Players can further explore their individual contribution to the group by trading their instrument sounds with their peers. This can be helpful for the perceptual separation of the timbre-oriented characteristic from the numerical aspects of the patterns.

2 Modes of Interaction

Interaction with the Musical Fireflies occurs in two distinct modes – the Single Player mode, where players convert numerical patterns into rhythmical structures, and the Multi Player mode, where collaboration with other players enhances the basic structures into polyrhythmic compositions.

2.1 Single Player Interaction

Each Musical Firefly is equipped with two default drum sounds that are operated by two buttons. When a Firefly is first turned on, it awaits the input of a rhythmic pattern from the buttons. The left button records an accented beat and the right button records a non-accented beat, using the same drum timbre. After two seconds of inactivity, the Firefly plays back the entered pattern in a loop, using a default tempo - ¼=80. This activity provides players with a tangible manner of entering and listening to the rhythmical output of any numerical pattern they envision, which leads towards an immediate conceptualization of the mathematical-rhythmical correlation. For example, the numerical pattern 4 3 5 2 2 would be entered and played back as follows:

● ○ ○ ○ ● ○ ○ ● ○ ○ ○ ○ ● ○ ● ○ (x loop)

(● = Accented note played by the left button
○ = non accented note played by the right button)

During playback players can input a second layer of accented and non-accented notes in real-time, using a different timbre. Each tap on a button plays a beat aloud and records its quantified position so that the beat becomes part of the rhythmic loop. Pressing both buttons simultaneously at any point stops the playback and allows the player to enter a different pattern.

2.2 Multiplayer Interaction

When two Fireflies that are playing different patterns using different timbres "see" each other (i.e. when their infrared signals are exchanged) they automatically synchronize their rhythmic patterns. (A similar interaction occurs when the firefly insects synchronize their light pulses to communicate in the dark). This activity provides participants with a richer, more complex rhythmical composition and allows for a fun and interactive introduction to polyrhythm. For example, if one Firefly plays a 7 beat pattern (● ○ ○ ○ ● ○ ○) and another plays a 4 beat pattern (● ○ ○ ○) then the players can hear the process of divergence and convergence as the patterns go in and out of phase every 28 beats, the smallest common denominator:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
7/4	●	○	○	○	●	○	○	●	○	○	○	●	○	○	●	○	○	○	●	○	○	●	○	○	○	●	○	○
4/4	●	○	○	○	●	○	○	○	●	○	○	○	●	○	○	○	●	○	○	○	●	○	○	○	●	○	○	○

While the two Fireflies are synchronized, players can also initiate a "Timbre Deal" in which instrument sounds are traded between the devices. Pressing either the left or right button trades both layers of the accented or non-accented timbre respectively. Each Firefly continues to plays its original pattern but with one button triggering the two new timbres that were received in the timbre deal. This provides players with a higher level of musical abstraction conceptualization since they now can separate the rhythmical pattern aspect of the beat from the specific timbre in which it is being played. Because the Fireflies network is richer after the interaction (i.e. each instrument now contains four different timbres,) the system can also encourage collaborative play where players are motivated by trading, collection and playing games by sending and receiving different timbres from different Fireflies.

3 Hardware and Software

The Firefly's casing is made of a 7.5''x5.5''x2.5'' 3-D printed fabrication, which is designed to be held with both hands while tapping the top-mounted buttons. The buttons are connected to two A/D converters on the embedded "Cricket" [9] - a tiny computer that is responsible for the musical algorithms.

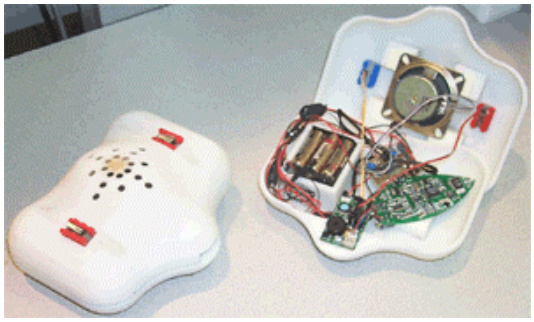

Figure 1. Two touch sensors on each Firefly are connected to a central microprocessor with infrared capabilities, which also serves as a driving force for the MIDI board, amplifier, and speaker. Each Firefly requires a power source of 6 AA batteries.

The Cricket, which is mounted at the front of the Firefly, is based on the Microchip PIC series of microprocessors. It can receive information from a variety of sensors and is equipped with an infrared system that allows for communication with other Crickets. The Cricket is programmed in a dialect of the Logo programming language. Application programs can be downloaded to the Cricket via its infrared communications port, allowing for players to easily rewrite and download applications and data to the Firefly. The entered rhythmic patterns are converted into musical messages using Cricket Logo general MIDI commands [10]. These are sent through the Cricket's serial bus port to the "MidiBoat" [11]

— a tiny General Midi circuit, which supports up to 16 polyphonic channels, 128 melodic timbres and 128 percussive timbres. In the current application, only the percussive timbres are being used. The audio from the MidiBoat is then sent to a top-mounted speaker.

4 Discussion

Several challenges were addressed in the process of designing a musical interaction that would focus on bridging the gap between the figural and the formal learning modes. One of the main challenges was to balance between the simplicity of operation and the depth of the musical interaction, between allowing for a fun, intuitive, and expressive activity as well as providing a meaningful educational experience. In order to address this challenge we tried to design a varied and rich infrastructure that will apply to a variety of players, who can be located in different places on the figural-formal axis. The Fireflies, therefore, were designed so that novices, with little formal education or experience would be able to experiment with stand-alone simple patterns using a single layer of rhythm. The instruments can also accommodate more advanced users, who can play with complex multi-layered interdependent patterns as well as reprogram their instruments using Logo. Our ultimate goal was to encourage players to advance from the simple basic interaction toward the rich, enhanced, and interdependent experience.

In order to address formal as well as figural musical aspects we had to come up with several compromises and trade-off modifications. For example, it was decided that the Fireflies would not capture the exact timing and rhythmic values of the entered taps. Rather, the algorithm merely records the sequence of accented and non-accented beats and plays them back in a default tempo. Although figural thinking would probably find exact rhythmic playback more intuitive and expressive, we reckoned that flattening the tempo would provide a better ground for comprehending the polyrhythmic collaborations, especially for children and novices. It was for this reason that we decided not to allow the input of rests. While it is clear that the addition of rests could have provided a richer more musical experience, experiments with a software-based version of the application showed that in the multiplayer mode players found it difficult and formally comprehend the polyrhythmic interaction. We faced a similar problem when deciding about the ideal value for the default tempo. For two-line rhythm patterns, a fast tempo sounded less mechanical and more fun to listen to than a slow tempo. However, when the Fireflies played their patterns too fast it became impossible to follow the divergence and convergence of different patterns in the multiplayer mode. We hope that the tempo chosen (¼ = 80) serves as a reasonable compromise between these two extremes.

As part of our efforts to balance between simplicity and depth of interaction we also had to decide about the number and complexity of controllers for players to interact with. We chose to implement only two discrete buttons and no continuous controllers in an effort to provide players with a simple, elegant and easy-to-learn interaction. This required us to impose a considerable amount of interaction onto these buttons while streamlining the software design. For example, instead of having a third mechanism to stop the rhythmic patterns we designed the Fireflies so that pressing the two existing buttons simultaneously would stop the music.

Another design challenge that we addressed was how to allow for an interesting and challenging multiplayer interaction that will stay coherent and will not confuse the participants. Several preliminary algorithms (such as trading the numerical patterns or mixing between patterns to create more complex ones) were ruled out since they failed to address this challenge by creating confusion and uncertainties among players. Finally we chose timbre as the parameter to be traded due to its "coloring" qualities, which do not complicate the already rich rhythmical texture, especially when more than two Fireflies are involved. The timbre parameter also seems to provide an educational value by helping to separate the instrument sound from the numerical patterns while maintaining the system's coherency.

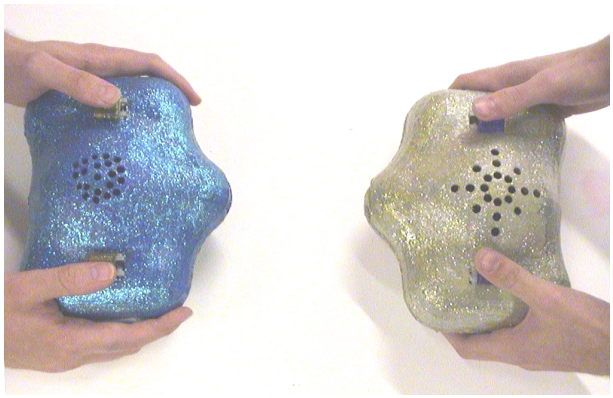

Fig 2: Two players interact with the finalized version of the Musical Fireflies.

5 Observation and Evaluation

Preliminary observations of group playing with the Musical Fireflies have been conducted, followed by discussions with the players. Participants were also asked to play with a Max-based [12] software version of the application and compare their experience with the tangible interaction that is provided by the physical Firefly objects. In general, players found the concrete aspects of playing with a physical object compelling in comparison to using a keyboard and a mouse. Subjects mentioned the unmediated connection that was formed with the instrument as contributing to the creation of personal involvement

and relationship with the musical application. Tapping real buttons and listening to the music coming from distinct physical sources also helped players to comprehend and follow the trading interaction in a more coherent manner than listening to computer speakers, especially when more than two Fireflies were playing simultaneously.

The observations and discussions also led to the identification of several deficiencies in the interaction design. Although carefully considered, the timbre trading function turned out to create some non-coherent consequences especially for novices who found it confusing. These prevented the full internalization of the desired educational value. In addition, trading timbres, a discrete operation that does not provide long-lasting interaction, led players to lose interest in the interaction after a few taps. Both these deficiencies are addressed in the Future Work section.

Subjects also expressed their wish to interact in larger groups that are comprised of several simultaneous players. The current application allows synchronization among up to three players and timbre trading between only two players at a time. This limitation is imposed by the line-of-sight infrared technology. In order to provide a full multiplayer experience new technologies and applications should be developed.

6 Future Work

Several hardware and software improvements are currently being investigated for the Fireflies. In terms of hardware we are exploring the possibility of implementing radio frequency transceivers that will allow for a group of up to twenty players to interact simultaneously. This will obviously require the development of new applications that will take advantage of the enhanced multiplayer possibilities. Other hardware enhancements that are being considered are improving the speaker acoustic qualities by using different materials and enclosures as well as embedding a sample-based recording chip that will allow players to record and playback their own sounds. This will hopefully add a new dimension to the personalization of the instruments.

We are also looking to enhance the musical application in Single Player as well as Multi Player modes. The new interaction will include recording and playing back of pitch-based sounds in addition to the pitch-less percussive sounds that are currently being used. This will hopefully allow for a richer melodic and harmonic musical collaboration while enhancing the educational value of the interaction. Several software-based efforts in this direction are already under development.

Other enhancements under development are the implementation of continuous timbre control using an embedded digital signal processing engine, and the implementation of continuous rhythmic manipulation that would allow players to edit their entered patterns and explore new rhythmic variations. In the multiplayer interaction, we are currently experimenting with longer performance oriented collaborations like providing players with the possibility to record patterns using their collaborators' timbres and allowing participants to receive other players patterns, edit them and create their own variation before sending them back to the group.

7 Acknowledgments

We thank Fred Martin, Bakhtiar Mikhak, and Prof. Tod Machover for their contributions.

References

[1] Gardner, H. (1983) *Frames of Mind*. New York: Basic Books pp. 110-112.

[2] Bamberger, J. (1982) "Growing up Prodigies: The Mid-Life Crisis," *New Directions for Child Development* 17, pp. 61-78

[3] Papert, S. (1980). *Mindstorm*. New York: Basic Books.

[4] Resnick, M., Martin, F., Sargent, R., & Silvernan, B. (1996). Programmable Bricks: Toys to Think With. *IBM Systems Journal*, 35 (3 & 4).

[5] Turkle, S. & Papert S. (1992) "Epistemological Pluralism and the Revaluation of the Concrete," *Journal of Mathematical Behavior* vol. 11, pp. 3-33.

[6] Weinberg, G., Orth M., and Russo P. (2000) "The Embroidered Musical Ball: A Squeezable Instrument for Expressive Performance," *Proceedings of CHI 2000.* The Hague: ACM Press.

[7] Weinberg, G. (1999) "The Musical Playpen: An Immersive Digital Musical Instrument," *Personal Technologies.* London: Springer-Verlag Publication, 3:132-136.

[8] Handel, S., (1984) Using Polyrhythms to Study Rhythm. *Music Perception*. Summer 1984, Vol. 11, No 4, 465-484.

[9] Martin, F. (1998) The Cricket web site. http://fredm.www.media.mit.edu/people/fredm/projects/cricket.

[10] Martin, F., Mikhak, B, and Silverman, B. (2000) Metacrickets – A designer's kit for making computational devices. To be published in *IBM System Journal* 2000.

[11] Smith, J. (1998) The MiniMidi web site. http://www.media.mit.edu/~jrs/minimidi.

[12] Winkler T. (1998) *Composing Interactive Music – Techniques and Ideas Using Max*. Cambridge Massachusetts: The MIT Press.