BeatTable: A Tangible Approach to Rhythms and Ratios

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ABSTRACT

Frameworks that create synergies across disciplines provide a powerful means for learning by relating concepts from the different fields that are usually difficult to grasp individually. We discuss the design of the BeatTable, a microworld that uses the relation between mathematics and music to engage learners in using ratios and proportions to create rhythms and learn about musical composition. The BeatTable is a physical table with a digital environment that can be controlled by tangible instruments, and through immediate auditory and visual feedback makes salient the relationships between math and music. With a low-floor, high-ceiling design philosophy, BeatTable provides learners the opportunity to build on their conceptions about music and to practice and hone their use of ratios and proportions. We present what our design choices, the technology used, and a description of initial user feedback.

Categories and Subject Descriptors

K.3.1 [**Computers and Eduction**]: Computer Uses in Education

General Terms

Performance, Design, Experimentation.

Keywords

Mathematics education, music education, knowledge-representation, physical computing, tangible user interfaces

1. INTRODUCTION

> "Music is the arithmetic of the soul, which counts without being aware of it." Leibnitz

The mathematical concepts of ratio and proportion, and the musical concepts of rhythm and tempo, are challenging topics for learners [1, 3]. To address this, we created the BeatTable: a learning environment that builds upon learners' previous conceptions in the domain of rhythm and proportion in order for them to learn those concepts. The BeatTable is a learner-centered microworld for exploring musical and mathematical concepts.

We embed a physical table with a digital environment that can be controlled by tangible instruments (see Figure 1), creating an experience that makes salient the important relationships between math and music. By providing immediate auditory and visual feedback, the BeatTable supports knowledge refinement and reorganization, instead of using replacement as the primary metaphor for learning [14].

Given the intrinsic relation between mathematical ratios and musical rhythm, our design seeks to engage the user in a low-floor, high-ceiling experience -- it's easy to get started, yet the BeatTable affords opportunities for increasingly complex activities over time, which can be perform in formal or informal settings [10]. The BeatTable uses physical activity to build representational mapping by offering users cognitively ergonomic and novel ways to dive into ratio and proportions while keeping the musical composition meaningful.

This also builds on previous work on rethinking the encoding of the knowledge and the representational infrastructure in the areas of mathematics, science [15], and music.

Figure 1: A photograph of the BeatTable

1.1 Problem Addressed

Learning to follow rhythms and different tempos of diverse musical pieces are two common problems for novice musicians and formal music students. This lack of tempo flexibility can be explained by research on changes in the human brain during learning rhythm [12]. Their study suggests that with practice, students increasingly came to depend on internal rather than external cues to time their rhythmic responses. Research on rhythm learning with children suggest that the incorporation of learning modalities into music teaching methods could result in more efficient learning of rhythm patterns [5].

Teaching and learning fractions, ratio, and proportionality in the middle grades are a well-known complex processes [2]. Problems in mastering those concepts persist through higher education and affect the learning performance of other ideas such as velocity. Extensive research has been done on the topic suggesting that one of the main strategies that students misuse when learning fractions, ratio, and proportions is to use additive rather than multiplicative solution methods [1].

Because of the analogous relation between tempo and rhythm, and ratio and proportion, improvement on the learning performance of the first pair of concepts can be expected if the understanding of the second pair of concepts is improved, and vice versa. This idea has been explored by several researchers [4, 7], who have suggested that mathematical understanding of fractions and ratios can be improved through music training.

1.2 Target Population

As a tool for learning basic musical and mathematical concepts in formal settings, the BeatTable is suitable for students from ages 9-12. As an instrument for exploring various aspects of rhythm and composition in informal settings, the BeatTable could be suitable for middle school and high school students as well.

For early music education, the BeatTable could be used to illustrate the essentials of beats and rhythms for students from 4th-9th grade. In both of these cases, the BeatTable would act as an enhancement to formal learning environment, where structured activities could help supplement math and music curricula.

The BeatTable is also suitable for informal learning environments as a tool for musical exploration. In museums, learning centers, and after school programs, the BeatTable could be helpful for middle or high school students to understand how beats decompose into layers, and can be used as an introductory tool for learning how to compose original beats and rhythms.

2. DESIGN AND THEORETICAL PRINCIPLES

2.1 The Importance of Representation

Formalized languages are invaluable for minimizing the time and space needed to convey information. However, in order to compress this information, formalized languages rely on abstractions that remove users from the core concepts being conveyed. As a result, formalized languages are particularly useful for those individuals who are already comfortable with the core concepts. For novice learners, however, these abstractions could act as a barrier to understanding the material.

With the BeatTable, we identify the core concepts that a learner needs to understand about rhythm: that rhythm emerges from the temporal distances between strong and weak elements. However, rather than attempting to convey these concepts using the formal language, we attempt to focus on these concepts through a different representation: using different instruments to convey emphasis, and using spatial distances to convey the intervals between sounds. Having different musical representations has shown to have benefits for learners in the past through tools such as Hyperscore [6].

2.2 Removing Barriers of Entry

With a musical instrument, one needs a lot of physical practice to be able to produce regular beats. A student learning how to play a musical instrument may not realize when they are not producing a regular beat, especially as they search for correct notes in a song.

An alternative way to generate beats is to use digital software, such as Apple's Garageband, or Ableton Live. However, while digital software reduces the barrier of entry caused by physical limitations, the complexity of the software raises its own barriers of entry. Furthermore, computer software is not conducive to physical and social collaboration, but is rather an individual activity performed solely on a computer.

The BeatTable attempts to address both of these barriers of entry. The digital structure of the BeatTable makes it so that a novice interacting with the machine could quickly produce a complex beat without physical training. The tangible nature of the BeatTable makes it so that musical beats are produced as the result of the user's direct manipulation of the instruments, and allows for multiple users to interact with the table at once, and this social collaboration with tangibles can help improve learning [12]. These features make it easier for the user to focus on creating beats and experimenting with distances and proportions, instead of struggling with physical and technological impediments to creating music.

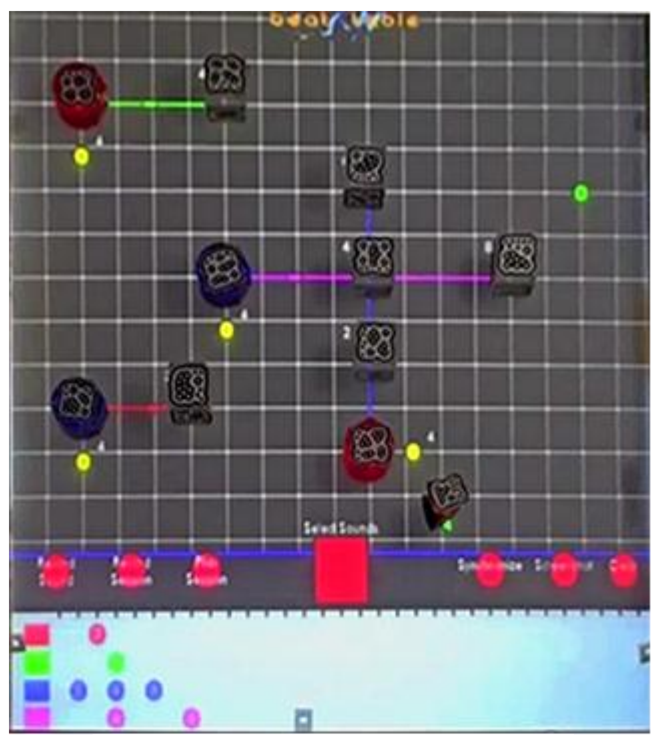

Figure 2: The BeatTable virtual environment

3. DESIGN

3.1 Generating the Music

Rhythm in the BeatTable is generated in a decentralized manner. Drawing on the concepts of complex systems and agent-based modeling [15], we designed the BeatTable such that the sound patterns and rhythms perceived by the user emerge as a global phenomenon from local interactions of *virtual agents* with their virtual environment. We refer to these virtual agents as *pulses,* the basic units that drive sound generation. The pulse is the analogy to time in sheet music. A pulse can travel through the 2D space of the music environment. The pulses act upon their environment, which is composed of a 2D plane of the table surface and of the virtual representations of the tangible objects that the user can manipulate (see Table 1). These objects consist of Pulse Generators, Sound Tokens, and Pulse Manipulators such as Redirectors and *Splitters.*

The basic mechanics are as follows: A Pulse Generator emits pulses that travel through the plane. As soon as a pulse hits an object, it activates it. If the object is a Pulse Manipulator, the path of the pulse gets modified; if the object is a Sound Token, the corresponding sound is played. There can be several objects of each type on the plane at once. Thus, the audible sound patterns emerge directly from the local dynamical behavior of the active pulses and the spatial configuration of the objects.

	The *Pulse Generator* emits pulses. There can be many active Pulse Generators at the same time. Each Pulse Generator has at least one visible pulse at a time. If there is no active pulse, it generates a new one. The speed of the pulses can be modified.
	A *Sound Token* has a specific sound assigned to it. The sound can be recorded by the user, or chosen from a database of samples. The user can modify the volume of the sound directly.
	A *Redirector* is an element that deflects a pulse at a 90° angle.
	A *Splitter* generates a new pulse with a new direction perpendicular to the original pulse path. This way, the user can break up the 1-dimensional pulse path into a tree-like structure by adding new branches to the path.

Table 1: Descriptions of the Tangibles

3.2 Distance: Making Proportions Salient

Our novel representation of music makes the proportional aspect of rhythm visually salient by creating a spatial representation of the temporal relationship of sounds. Rhythm generation is now based on the distance of the Sound Tokens and the Pulse Manipulators with respect to the Pulse Generator. The proportions of those distances determine the beat, the modular unit of music. Thus, recurring beats arise whenever these proportions stand in certain relationships to each other.

The importance of distance ratios for rhythm generation is foregrounded in two ways: first, the distance of each object to the Pulse Generator is displayed directly on its upper left corner. Second, the 2D space of the grid is displayed in a linear visualization on the bottom of the table screen, as seen on the bottom of Figure 2.

3.3 Instruments: Making Emphasis Salient

The role of emphasis in rhythm generation is manifested in the different sounds of each Sound Token. For example, a bass drum sound inherently express a stronger emphasis than a Hi-Hat sound. Thus, given a rhythm, a user can start to explore what happens to the rhythm when the Sound Tokens that make up the rhythm are interchanged. A user can record new sounds through a microphone that are made immediately available to the user.

3.4 Continuous vs. Discrete Space

Instead of using a continuous space, we decided to discretize the space into a grid with 90° angles. Instead dealing with real numbered Euclidian distances, the grid enables learners to describe distances between objects as integer multiples of the grid spaces. Thus, the grid representation enables learners to work with exact metrics, which not only make the ratios more salient, but is also more reflective of how music works.

4. IMPLEMENTATION

4.1 The Physical Environment

The physical environment comprises of a personal computer, a translucent table as the main user interface, and tangible objects that interface with the virtual environment. The input to the computer comes from a video camera on top of the table that is aimed at the table surface (as seen in Figure 1). Underneath the table, there is also a projector that outputs the virtual environment on the underside of the table top, that is visible from the upper side as well. Additionally, there is an audio system for the audio generated on BeatTable.

4.1.1 Hardware Components

Only standard, off-the-shelf components are used for the table, the camera, the computer and the projector, in order to facilitate its replication. The table is designed such that three users can interact with the system at the same time. This fosters collaboration in the exploration of rhythms, which we consider as a crucial aspect to the convivial experience of music making. Tangible objects are made of acrylic and created with the use of a laser-cutter, and are identified by the computer using printouts of fiducial markers that are glued to the tangible objects.

4.1.2 Camera

It is important to us that the BeatTable can be used in a variety of different settings, independent of light conditions. With the camera on the top, BeatTable functions well also under brighter conditions, as the fiducial markers are better recognizable then from underneath.

4.2 The Virtual Environment

4.2.1 Processing

The virtual environment has been built in Processing, an open-source Java-based object-oriented programming language. The advantages of Processing for our purposes are twofold: first, the reacTIVision framework provides a powerful and robust event-based client, which allows us to process interactions with the tangible objects in real-time. Second, processing comes with a wide range of sound libraries that enable real-time audio processing. Specifically, the audio engine of our system is based on Beads, an open-source audio software library that enables efficient parallel processing of audio events.

4.2.2 reacTIVision

The interface between these two environments builds on reacTIVision, an open-source toolkit for tangible interactive technologies. This computer vision software is able to track tangible objects by means of the fiducial markers. The distortion engine built into the reacTIVision framework allows for proper calibration to align the virtual projection position with the physical object position.

5. DISCUSSION AND CONCLUSION

We tested the BeatTable in informal environments where dozens of University students were able to try it out. In these initial observations, users greatly enjoyed generating beats and were quickly able to produce rhythms by placing instruments in proportional distances from each other, which is exactly what we had hoped. Most of the users comment on the ratio and proportion patterns they found while generating the rhythm, making statements such as, “I think multiples of 4 sounds better”. Users did not seem to use the graph at the bottom very much, suggesting that it might be best utilized as an optional feature for educators or should otherwise be further developed.

We also conducted a 30-minute user observations with a think-aloud protocol, where the user, who had no formal musical training, was quickly able to generate their own beat just by placing the instruments at good proportional distances from one another. The user were very engaged and reported that they would like to continue playing with BeatTable after the 30 minutes.

In the future, we hope to conduct further studies that can validate and improve the effectiveness of our design.

6. ACKNOWLEDGMENTS

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