BEATBLOCKS

MEAM Senior Design Final Report

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Abstract

BeatBlocks is an inventive product that helps children comprehend and interface with complex musical composition elements like notes, rhythm, and layering. Through fully stackable and connected blocks, our solution teaches the nature and notation of music, making it easy for users to create musical sequences. BeatBlocks leverages 3 simple tools - rhythm blocks, pitch blocks, and tracks - to transform abstract ideas - like tempo, tone, and musical measures - into easy-to-understand, tangible concepts. Additionally, BeatBlocks' digital interface allows users to view their live compositions as traditional sheet music and participate in engaging, gamified musical exercises.

The project presented is a digitally-empowered, innovative reimagining of [the classroom tool] created by elementary school music teacher, Abby Blair. Although Blair's invention has proved to be effective in musical classrooms all over the country, it faces three major issues: a lack of supporting technology, a need for instrument access, and a need for professional instruction. Our team aims to combat these issues by creating a smart, electronically-powered device that enables the benefits of Blair's tool to be accessible in home environments. With a target audience of K-3 children, BeatBlocks is a low-barrier tool for teaching musical insight that prepares users for greater success with formal music or instrument education. Ultimately, BeatBlocks aims to combat falling engagement in traditional education by solidifying musical confidence in the home before children begin traditional music classes past 3rd grade.

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Introduction

Background

Exposure to music education has been proven to have significant developmental and cognitive benefits in young children. A study by Glenn Schellenberg in 2004 linked musical training to higher IQs and effective social behavior [Schellenberg, 2004]. Further studies found that a close relationship with music was also correlated with boosts in high-order auditory skills such as auditory processing, phonological awareness, and prosody [Carioti, 2019]. Additionally, the effects of musical exposure have been proven to last beyond childhood, with studies finding that adults who had been trained in music exhibit high performance on verbal memory tasks, verbal intelligence, language processing, arithmetic, and reading skills [Carioti, 2019].

Although the benefits of music education are well studied, this subject still faces difficulty staying relevant in modern curricula. In a longitudinal study spanning four years focused on California public schools, it was found that while enrollment increased 5.8%, the percentage of students enrolled in music classes declined 50% [Music for All Foundation, 2004]. Similar observations were seen in Florida where students were followed from kindergarten through 8th grade. Of the 31,332 students, only 22% enrolled in a middle school music class [Major, 2010].

With declining interest in music among young audiences, how can we promote creative engagement and preserve the positive learning benefits of music education?

Causes for Falling Engagement

Several stakeholders were surveyed throughout the development of our solution. The stakeholders interviewed had expertise as music students, music educators, music producers, and child development researchers.

From stakeholder insights as well as published research papers, our team found that falling engagement rates could be linked to four main factors:

1) **Lack of parental engagement:** It has been shown that parents generally value music education and that parental involvement in their child's music education is linked to musical achievement [Zdzinski, 2002]. However, many parents face barriers to engaging in music with their children due to a lack of knowledge, lack of time, and financial constraints.

2) **Lack of confidence in musical talent:** Christopher Venesile, a trainer for K-12 music instructors and choral instructor of over ten years, found that current music curricula are designed to emphasize the top of the class or naturally gifted students. As a result, many students are unsure of what music can offer them and if they can benefit from further lessons [Doran, 2017].

3) **Perception that music lessons are expendable:** A study by Diane Stjern found that the number one reason cited for students dropping out of school music electives was due to students wanting

to focus their time on other electives and classes. One student cited, “I was involved in other extracurriculars and I was getting too busy." [Stjern, 2021].

4) **Lack of access to instruments:** Schools with high low-income populations are less likely to have music classes than wealthier communities [Mongeau, 2019].

Impact of Abby Blair’s Beat Blocks

Despite challenges in proving the worth of music education, engaging students, and fighting for funding, many individuals are passionate about teaching music to the next generation. Because of the aforementioned hurdles, teachers are challenged to come up with inventive and cheap ways to communicate complex ideas while keeping students engaged in the classroom.

Abby Blair, an elementary school music teacher of over ten years, did just this and her solution has had an overwhelmingly positive impact in music classrooms around the country. In an interview with our team, Blair stated that Beat Blocks were born out of frustration when she realized that she had to teach music “whether the kids wanted to learn or not.” To create the original Beat Blocks, Blair glued paper notes to her son’s Mega Blocks and took them to class. Immediately, students were mesmerized by the new tool and began to understand lessons on rhythm, pitch, and tone in a tactile and engaging way.

Today, Beat Blocks have spread across the country and have had similar effects in numerous music classrooms [Blair, 2016]. Our team has partnered with Abby Blair to leverage her groundbreaking concept to address falling engagement rates in music classrooms.

To combat two major reasons for falling engagement -- lack of parental engagement and lack of confidence -- our team has decided to bring Beat Blocks into the home to give students access to musical learning opportunities at a young age. Our hope is that this tool will solidify children's confidence in musical concepts by the time they reach traditional music classes, and allow parents to engage in their child’s musical interests whether they have a background in music or not.

Working with Beat Blocks in music classrooms

Value Proposition

BeatBlocks elevates current tangible music learning tools to promote an understanding of music notation, composition, and independent learning. By providing children with an intuitive physical and digital interface, BeatBlocks supports informal music learning in home environments with a minimal barrier to entry.

Social Impacts of the Solution

As BeatBlocks aims to support music learning with a minimal barrier to entry, the product has clear cultural and social implications, with goals to improve public education and cultural development.

Public health, safety, and welfare: Strong music education programs are rare, especially in underrepresented communities. Further, the costs of advanced music learning programs like private lessons make them less accessible. To combat this, informal learning offerings like BeatBlocks have been seen as a catalyst for social justice in music education, especially given the well-known developmental benefits of early stage music learning [Green, 2015].

Global, cultural, and social factors: In response to declining rates of engagement and enrollment in elementary school music classes, music educators have cited a "pedagogical tipping point" in music learning. In The Oxford Handbook of Technology and Music Education, it is stated that the chasm between youth's musical interests and that which is valued in traditional music education is often forgotten, such that curricula that prioritizes older Western music may seem distant and approachable to younger audiences from different backgrounds. As such, digital music education presents a unique opportunity to re-engage these audiences and extend participation to this marginalized group of young and beginner musicians. We hope that BeatBlocks is able to re-emphasize the importance of music in light of these cultural and social shifts in music education.

Environmental and economic factors: Given the digital and physical nature of the BeatBlocks product, we expect this offering to have a longer lifetime value than other types of educational toys in the market. Upon purchase of the toy, users can download the digital app for free on the app store and connect their devices via Bluetooth. Within the app, we may offer in-app purchases that allow users to buy more game options. Basic services like initial gameplay options will be provided for free, while more advanced game options can be purchased in bundles by the user. Additional blocks and secondary tracks may also be purchased separately to extend the length and complexity of buildable compositions. As such, unlike other mass-manufactured toys, BeatBlocks comes with a less taxing environmental cost of manufacturing and a more effective, fair pricing model for buyers.

Characteristics and Constraints

Optimal System Characteristics

Characteristic	Stakeholder Interview	Interpreted Need
Gamified	“Game-like activities provide musical insight at a young age.”	Supports engaging activities that require strategy and understanding of musical concepts.
Cost	“Most types of children's toys available on the US market are not really expensive.”	Competes with current electronic music toys on the market, priced around $20 to $40 for a pack of 53 blocks.
Age	“Music ignites all areas of child development and skills for school readiness.”	Survey results of individuals with elementary music experience suggested a targeted age range of 5 to 8.
Tactile	“Students were not as interested when there was no hands-on component.”	Has at least one physical component that drives user interaction, with a scale from 1 component to 5+.
Intuitive	“Reasons for low levels of at-home music engagement included lack of parental knowledge.”	System forms based on survey results of individuals with elementary music experience.
Safe	“Adult supervision and instruction is required for typical instruments.”	Adherence to major international toy safety standards ISO 8124, EN71, and ASTM F963.

Table 1. Optimal system characteristics

Physical Engineering Standards

Acceptability of Electronic Assemblies (IPC-A-610G)
This standard is a comprehensive standard for the design and manufacture of electronic assemblies. It covers almost all aspects of electronic assembly design including soldering, wiring, component mounting, connectors, and more. This standard will be useful as a reference point for the electrical stage of the design process.

Dimensioning and Tolerancing (ASME | Y14.5)
This standard was developed by ASME as an authoritative guideline for the communication format of geometric dimensioning and tolerancing (GD&T) used in engineering drawings, models, and related documents. GD&T is important for communicating design intent and aids in producing uniform and exact parts throughout the manufacturing process. This standard will be important throughout the design process for our solution and aid us in creating optimally sized parts that are accurately communicated to manufacturing teams.

Occupational Safety and Health Administration Standards (OSHA 1910.211(d)(44))
This standard exists to reduce injuries from operating equipment where it is possible for a part of the body to be caught between moving parts. Our solution must take into account any “pinch points" for our users (regardless of hand and finger size) so that no users are accidentally injured when using our device.

Digital Engineering Standards

Google Play Developer Policies
There is a group of standards that apps available on the Google Play Store have to adhere to. These include but are not limited to: avoiding restricted content, implementing minimum functionality, and being respectful of user data. The child and family-oriented policies in particular are important, since children are potential users of our solution. These standards are extremely important, such as following the Children’s Online Privacy Protection Act (COPPA). Similar app policies are available for the Apple App Store.

International Standard, Software Engineering- Lifecycle Management (IEEE | 24748-3)
This standard establishes guidance to implement a common framework for software life cycle processes, with well-defined terminology, so that it can be referenced by the software industry. It also “emphasizes the importance of establishing a strategy, planning, and the involvement of stakeholders, with the ultimate goal of achieving customer satisfaction.” Examples of “best-practices” mentioned in the standard include developing satisfactory and feasible solutions |or the set of derived system/software requirements and “maintaining the integrity of the operational concept and reflecting the organizational objectives for the system.” It also suggests methods and approaches for every step of lifecycle management.

ISO International Standard ISO/IEC 14882:2020(E) - Programming Language C++
This standard governs idiomatic C++20 code. Arduino is based on a subset of C++, so not all modern functionalities are available. However, this standard gives us a strong guide to the specifics of C++. This helps ensure that our C++ code is safe, maintainable, and readable. This standard is created by the C++ committee and is the authoritative guide for all features C++.

Design Impact of Standards

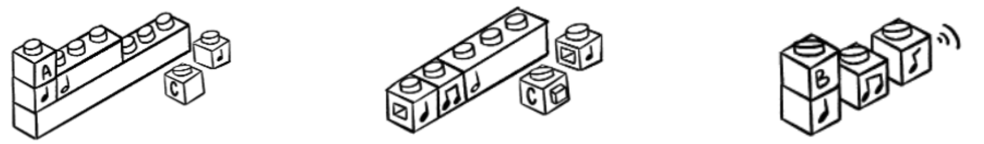
Physical Changes
The IPC-A-610G and ASME | Y14.5 standards mentioned above were kept in mind while we designed and mocked up our device, making sure to follow electrical engineering guidelines as well as digital modeling rules. We paid particular attention to OSHA 1910.211(d)(44) because of our target audience of children -- safety was a huge consideration due to both pinch points and the potential for electrocution due to exposed electrical leads, so we ensured that clicking the blocks together does not require much effort and the powered voltage pins can never be accessed.

Digital Changes
All three of the digital guidelines were followed when developing the code, since most deal with best practices and proper functionality. IEEE | 24748-3 was particularly beneficial to our product management, enabling us to create, test, and revise at maximum effectiveness.

Design, Engineering, and Realization

System Downselection: Tracks

There were three main systems we considered for our track subsystem. First, is a 8-count combinable track. The system uses different layers for each type of note and pitch, allowing the user to combine blocks to come up with melodies. Each individual block only represents either a note or a pitch, not both. Second, is the direct track method, where each block has both a note and pitch, and are placed next to each other to create melodies, as opposed to stacked. Finally, is the proximity detecting block system. These blocks would be stacked similar to the first, but would not be connected along a singular track.



Track
8-count,
combinable tracks

Direct
Blocks connect to
one another

Distance
Measured with
proximity detectors

Out of these systems, the first, the 8-count system, was chosen. Intuitively, there are a few reasons why we initially thought this system would be more effective. First, the connected nature of the singular track allows students to visualize how the combination of pitch and rhythm come together. Compared to the other systems like the direct track method, having each block have both the note and rhythm does not elucidate how both can be combined. Second, the combined nature of a singular track also allows users to understand how each individual element comes together for a single melody. This hypothesis was validated with our initial user feedback on our designs, and was further validated across our key system characteristics, as shown below.

	Gamified	Cost (with 10% margin)	Age Range	Number of Physical Components	Intuitive	Safe
Track	Yes	$34.32	5 - 8	5+	66.7%	Yes
Direct	Yes	$192.97	7 - 10	5+	33.3%	Yes
Distance	Yes	N/A	10+	5+	0%	Yes

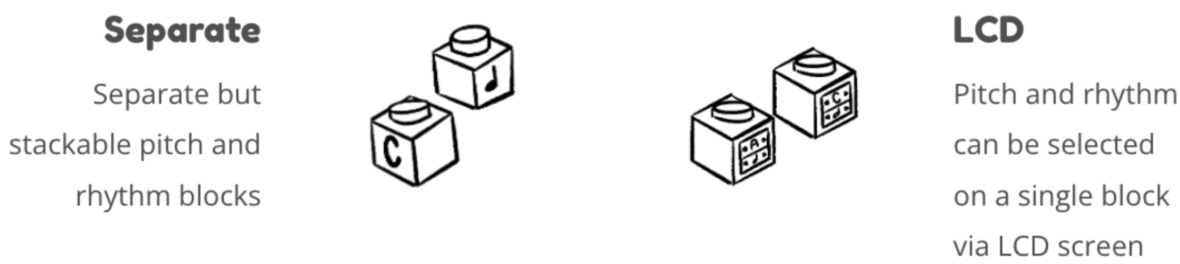
Table 2. Track downselection

The intuitiveness standard was measured via user testing, where we depicted each potential system and had users rank which they found the most intuitive to use. This allowed us to comparatively determine which was the most intuitive system.

System Downselection: Blocks

Two main subsystems were considered for the blocks. First, is a separate but stackable pitch and rhythm block system. Second, is a single block with an LCD, indicating both pitch and rhythm. Similar to the reasoning above for the tracks, the former system was chosen. Having separate blocks representing concepts of pitch and rhythm show users how these separate and individual concepts come together to create a musical melody.

The optimal system was selected in a similar process to the tracks, with the same key system characteristics being used as the criteria for selection. Based on the results, the separate block system was chosen, as it fulfilled all of our key system characteristics.



	Gamified	Cost	Age	Tactile	Intuitive	Safe
Separate	Yes	$8.16	5 - 8	5+	83.3%	Yes
LCD	Yes	$183.06	10+	5+	16.7%	Yes

Table 3. Block downselection

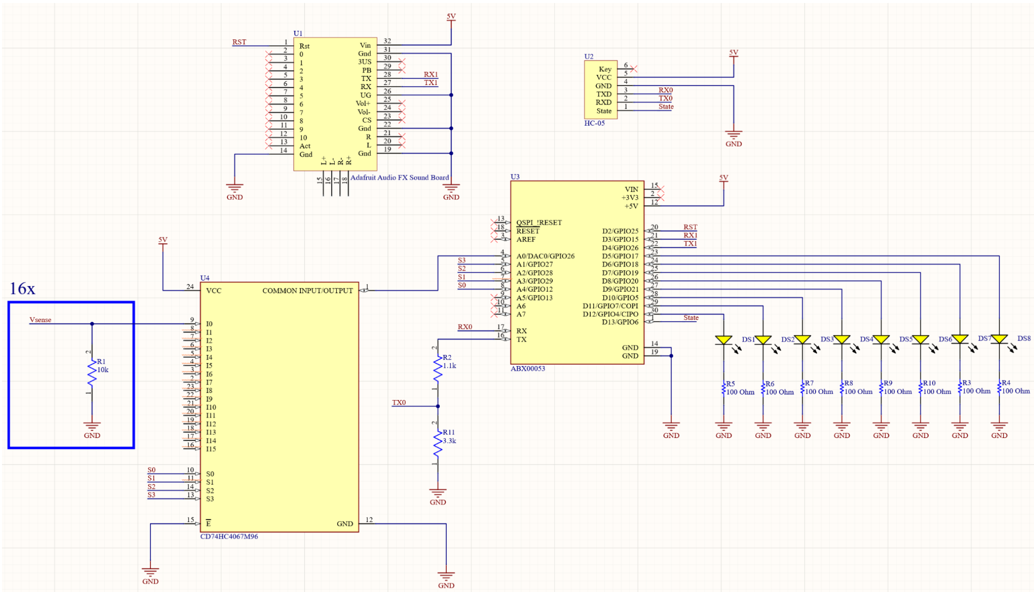
Final System Form

Physical Form

Digital CAD model

The physical components include rhythm blocks, pitch blocks, and primary and secondary tracks. Similar to the structure of LEGOs, the rhythm and pitch blocks are stackable and can be connected to the track, a docking bar that can hold eight beats (or blocks). The musical aspects of the pitch and rhythm blocks are combined to create the new musical note. After completing a track, users can listen to their compositions using the play and pause buttons. A speaker hosted on the track will output the audio of a track. Multiple tracks can be combined to create larger compositions through secondary track additions. The rhythm and pitch blocks are cast using custom molds and house custom electrical connections that are designed with safety and robustness in mind. Each pitch and rhythm block is identifiable to the track through a unique resistor value embedded in the block. The primary track houses LEDs for indication of which note is being played, an Arduino, an audio module and amplifier, a Bluetooth module, and supporting circuitry and buttons. Using Bluetooth, a user can connect the system with the digital app to visualize and interact with their compositions.

Electrical Integration



Electrical schematic

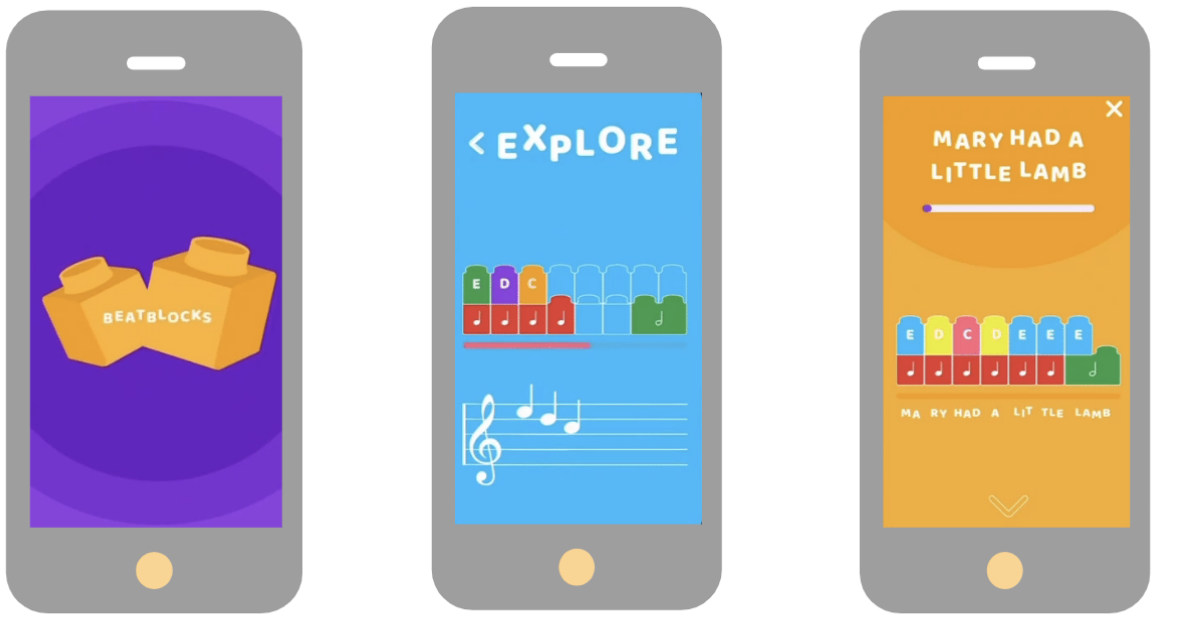
The electrical system consists of an Arduino Nano, an audio module and amplifier board, a 16 bit analog multiplexer breakout board, an HC-05 Bluetooth module, buttons, LEDs, a speaker, and supporting components. The circuit is built on a perfboard housed within the track.

When a block is connected to the track, an analog voltage V_{sense} is produced from a voltage divider circuit consisting of a 10 kΩ resistor and a resistor of a unique value embedded in the block. The Arduino detects which blocks are plugged into each of the 16 possible positions by measuring this voltage through one of its analog inputs. An analog multiplexer is used to expand the Arduino's analog inputs to the required 16. The V_{sense} leads, which are exposed on the top of the track, are pulled to ground when not connected to a block, while the 5 V leads are enclosed within a small female connector, preventing access to any charged leads.

An 8 Ω speaker is driven by an Adafruit Audio FX Sound Board to generate sounds during playback. The board has 16 MB flash storage which is preloaded with sounds. The Arduino communicates with the sound board through TTL UART serial communication. When the play button is pressed, one of eight LEDs lights up when each note plays.

Finally, the Arduino uses an HC-05 Bluetooth module to enable wireless communication with the Android app, transferring data on the state of the track.

Digital Form



Renderings of app UI/UX

The digital application offers two user experiences:

1) Explore Mode offers live sheet music notation and visualization. When a user combines blocks and connects them to the track, this feature displays the real-time block configuration in sheet music notation.

2) Play Mode offers song-based games that test the user's composition skills. In this mode, the user listens to a song and attempts to recreate the right track with the rhythm and pitch blocks. The user then submits the track, and the app displays a live evaluation of the submitted composition. Based on the app's feedback, users can iteratively adjust the track until they successfully recreate the song.

In both of these user experiences, the visual block and notation elements can be manipulated by the physical play, pause, and loop buttons. When a user presses play in the Explore or Play Mode, the app will show the correctly-timed progression through the song and highlight the block location that corresponds to the sound being played from the track. During the loop feature, the same song segment will be played repetitively and displayed on the screen. At any point, the user may pause the segment by pressing the pause button from the track and the animation will stop at that point and block position. This app-side musical representation paired with the synchronized physical prompts (the note blocks being played and lighting up) helps the user better understand and memorize what the different note combinations may sound like. To support this real-time rendering of the visual app, we rely on robust cross-communication from the Arduino to the device hosting the app. The app itself is coded in Java with Android Studio, featuring visual assets made from scratch in Figma.

System Performance

Demographics and Validation Methodology

- **Parent surveys:** We conducted surveys of parents who have or have had children in grades K-3 to answer two core questions: do parents value musical education, and would they buy BeatBlocks for their children?

- **Zoom interviews:** Zoom interviews were held with children in our key age demographic, where we mimicked the functionality of BeatBlocks virtually by showing various physical pieces and asking children what they wanted to do with it. We then replicated the guided actions with the actual BeatBlocks device. We used these interviews to test how long it took for children to understand the product and start composing with minimal instructions, and to test whether children were excited by the interaction.

- **Physical testing:** We tested the physical BeatBlocks component with our college peers to evaluate the physical component of our design. We used these tests to confirm whether users were able to easily add and remove blocks, and whether the shape or size of the product made sense.

Results and Analysis

Our parental survey found that a majority of the 30 respondents believed in the importance of music education and actively supported their children in musical pursuits, which confirmed some of our previous stakeholder and market research. Notably, more than 25 parents responded that they would purchase BeatBlocks, indicating a high willingness to buy.

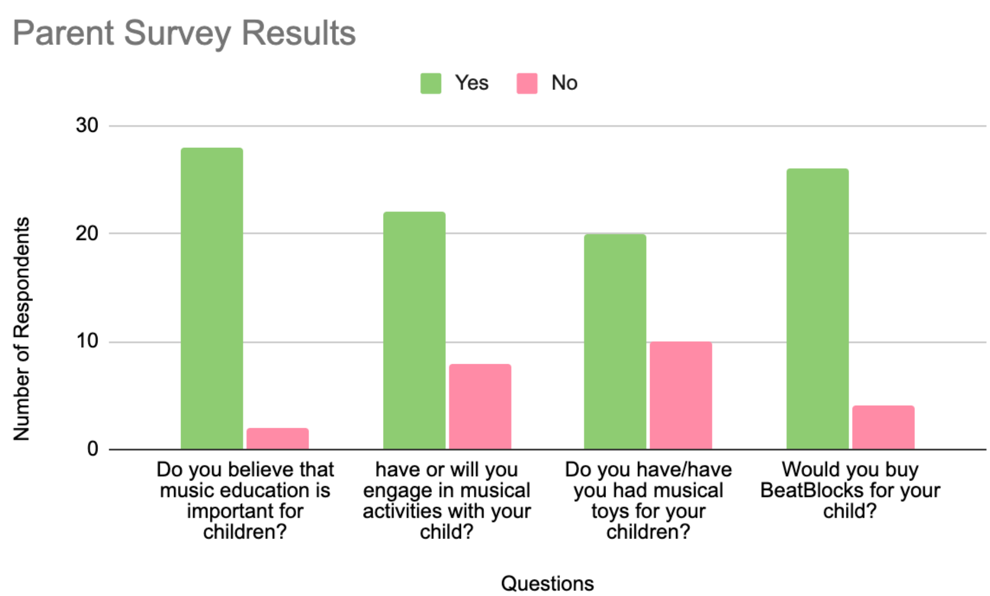


Figure 1. Parent survey results

Our other survey conducted on ten of our college age peers found that the physical design of the product was robust and easy to use. Considering our target users of younger children, however, these results may not be indicative of how a typical user may feel about BeatBlocks.

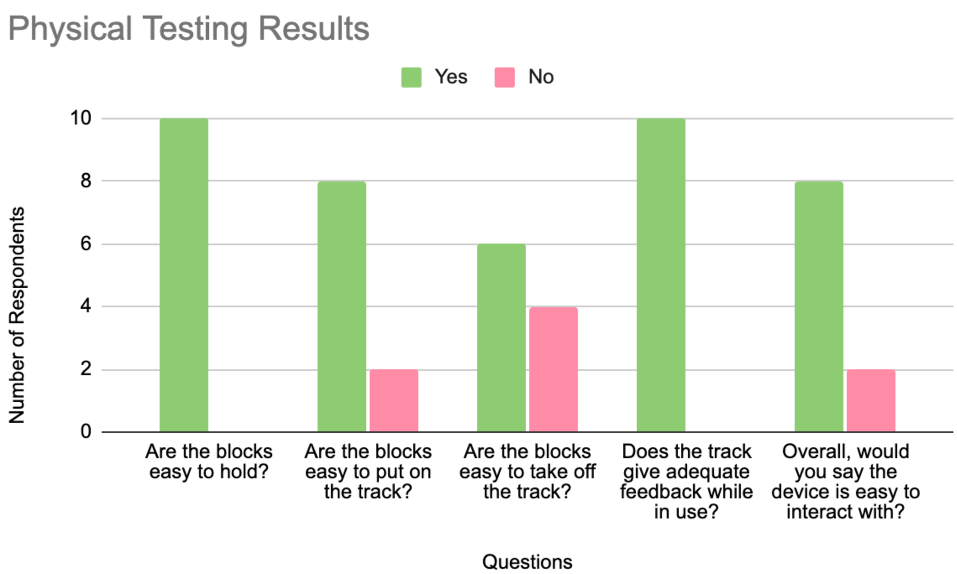


Figure 2. Physical testing results

Finally, for our Zoom interviews we were able to talk to three children aged 5, 7, and 7. We found that the two 7 year olds were able to easily understand how to begin composing, as evidenced by a quick realization that they were supposed to stack the blocks on top of each other. A full composition was made in 3 minutes and 5 minutes, respectively. Although the 5 year old required the most assistance with explanations of which blocks to stack on top of each other, they were able to start composing freely after working through a demo with the team members. A full composition was made in 8 minutes. All three children were excited to see the blocks make sound and light up when connected, exhibiting interest and laughter. These interviews allowed us to better measure how our system characteristics of intuition, safety, and tactileness fared in BeatBlocks, and overall were a success.

Conclusions and Future Work

Major Findings

Overall, our team concluded that BeatBlocks is a viable product that has potential to make an impact on musical learning in the home. We were pleased with the validation results and by the positive reaction during the final exhibition. As evidenced through our testing above, we found that 100% of children were able to complete their first composition in under 8 minutes, 86.6% of parents would buy BeatBlocks for their children, and 80% of peers were approving of the physical interaction.

Moving forward, we would like to expand on our validation by testing with children in real life and iterating on the electrical connection point between blocks to improve our physical interaction rating.

Out of Scope Ideas

In addition to the existing prototype, we see the potential to explore new ideas and implementations like adding more complex physical elements (tracks, extra blocks, etc.) and creating our ultimate go-to-market strategy.

Secondary tracks: Currently, the prototype has one track that can be played, paused, and looped. This allows for more independent creative exploration likely through informal learning in the home. By adding secondary tracks, Beatblocks could support more complex compositions that contain more than two measures. Further, a strong benefit of early music education is the collaborative element that encourages children to work together and develop positive social skills. Secondary tracks could be introduced in a classroom setting that would allow multiple users to compose music together.

Different instruments: BeatBlocks features piano notes when playing the compositions aloud. In the future, it would be rewarding to explore playing the notes from different instruments. This could be easily configured by uploading more sounds to our Arduino and creating an option for the user to switch instruments. On the application end, we could even allow users to store and save compositions made in one instrument and combine, or layer them, to create a composition with various different instruments. This would extend the age range of BeatBlocks' target audience, as it could offer introductory lessons in digital music composition.

Sales and expansion packs: Similar to LEGO, the value of the Beatblocks product increases with additional purchases. With knowledge of the competitive landscape, BeatBlocks plans to sell the physical device with an initial set of blocks (the track, rhythm and pitch blocks) through a brick and mortar retail model or e-commerce model. The physical device will be sold for $34.32. Upon purchase of the toy, users can download the digital app for free on the app store and connect their devices via Bluetooth. Additional blocks and secondary tracks may also be purchased separately to extend the length and complexity of buildable compositions. These additions to the original BeatBlock set will have higher profit margins as individual blocks are relatively cheaper to make. The continuous release of new expansion blocks will help us profit off of customers who want a more customizable experience without a high price barrier that might dissuade some customers. Within the app, we may offer in-app purchases that allow users to buy more game options. Basic services like the Explore feature and some initial gameplay options will be provided for free, while more advanced game options can be purchased in bundles by the user. Alternatively, we may offer these additional features through a subscription model, which would offer a more consistent cash flow.

Next Steps

Our initial prototype would ideally be tested in person with children, but due to time constraints and potential liabilities we were unable to work directly with kids. For next steps, our team would like to prioritize working directly with children to get feedback on the physicality of our device as well as the concept. Additionally, our team will be focusing on iteration of the electrical connections to incorporate more robust, spring loaded connections into our system. After further validation our team would love to create a manufacturable version of BeatBlocks with design considerations for manufacturability and assembly of a mass produced product, and possibly move forward with a commercialized product.

Statement of Roles

Tessa Fang: Mechanical Engineering | Project Management
Tessa was primarily responsible for physical realization of the final product. This was conducted through CAD design in solidworks, iterative prototyping, and electrical integration of custom build connectors. Tessa worked closely with Isaac to ensure seamless integration of complex electronic circuits. In her Project Management role, Tessa worked with Hannah to keep track of deadlines, run weekly meetings, and handle major project submissions for the team.

Hannah Wang: Computer Science | Project Management
Hannah worked on the digital realization of the final project with the Computer Science team, specifically focusing on front end design of all assets and app outlook, implementing advanced user interaction and animations. In her Project Management role, Hannah worked with Tessa to keep track of deadlines, run weekly meetings, and handle major project submissions for the team
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Jun Park: Computer Science | Outreach and Testing
Jun worked on the digital realization of the final project with the Computer Science team, specifically focusing on connecting the app with the physical device through Arduino code. In this position, Jun was responsible for Bluetooth connection, sound translation, and signal transmission. In his Outreach and Testing role, Jun worked with Lindsey to manage all outside communication with stakeholders and testing partners.

Lindsey Yu: Computer Science | Outreach and Testing
Lindsey worked on the digital realization of the final project with the Computer Science team, specifically focusing on implementation of back-end development for the Android app. Lindsey's work supported user interaction with the app's visual representations of the block and musical elements. In her Outreach and Testing role, Lindsey worked with Jun to manage all outside communication with stakeholders and testing partners.

Isaac Blinn: Electrical Engineering | Budgeting and Purchasing
Isaac was responsible for developing the connection between the physical and digital realization of the prototype. In this position, Isaac focused on developing custom circuits, wiring custom perf boards, and heading the ideas for a logical method of digital and physical interaction. In his Budgeting and Purchasing role, Isaac managed orders and kept track of the team budget.

Acknowledgements

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- **Mark Yim**: *Primary Advisor, Professor, Mechanical Engineering and Applied Mechanics*
- **Abby Blair**: *Primary Stakeholder, Elementary School Music Teacher, Creator of Beat Blocks*
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- **Andres Voyer**: *Teaching Assistant advisor, Integrated Product Design Masters student*
- **Sangeeta Vohra**: *Director of Integration, Jerome Fisher M&T Program*
- **Peter Szczesniak**: *Manager, Manufacturing and Fabrication Services*
- **Peter Bruno**: *Educational Laboratory Coordinator, Manufacturing and Fabrication Services*

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