Experience and Ownership with a Tangible Computational Music Installation for Informal Learning

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ABSTRACT
In this paper we present a preliminary design and initial assessment of a computational musical tabletop exhibit for children and teenagers at the Museum of Design Atlanta (MODA). We explore how participatory workshops can promote hands-on learning of computational concepts through making music. We also use a hands-on approach to assess informal learning based on *maker interviews*. Maker interviews serve to subjectively capture impromptu reflections of the visitors' achievements from casual interactions with the exhibit. Findings from our workshops and preliminary assessment indicate that experiencing and taking ownership of tangible programming on a musical tabletop is related to: *ownership of failure*, *ownership through collaboration*, *ownership of the design*, and *ownership of code*. Overall, this work suggests how to better support ownership of computational concepts in tangible programming, which can inform how to design self-learning experiences at the museum, and future trajectories between the museum and the school or home.

ACM Classification Keywords
H.5.5. Information Interfaces and Presentation (e.g., HCI): Sound and Music Computing: Systems; K.3.2. Computers and Education: Computer and Information Science Education: Computer science education

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Author Keywords
Tangible User Interfaces; Hands-on Learning; Informal Learning; Computer Science Education; Algorithmic Composition; Music Performance; Field Study.

INTRODUCTION
During the last decade there has been a flurry of research on tabletop tangible user interfaces (TUIs). However, much of this research has been conducted in laboratory settings, creating a call for an increase in real-world or "in the wild" studies that tackle real-world problems [8]. Tabletop environments have been researched as a suitable platform for supporting collaboration and informal learning in education [12], with examples in the classroom [3, 4, 48] and in museum settings [9, 23, 36]. Abstract and complex concepts have been implemented and studied in museums within short-term and casual interactions, as discussed in [9] on environmental sustainability, in [23] on animal species or in [36] on cultural heritage. Computing is an important 21st century skill that has struggled to engage a diverse student population. It is an open question whether or not computational concepts can be learned on tabletops in a way which raises curiosity and maintains participant engagement even beyond the collaborative or casual experience.

Our research explores the informal learning of computational concepts using the TuneTable, a tangible tabletop interface for easily making music through code. The interest remains on whether or not, and how, children and teenagers can informally gain content knowledge in and positive attitudes towards computing in public settings by means of making music. Informal learning in museums is related to *experience* and *ownership* from interacting with exhibits or environments. Experience relates to learning from hands-on explorations, and ownership relates to the motivation for self-learning after being exposed to a learning activity. This research focuses on the nature of experience and ownership in tangible interaction. This approach is in alignment with Dewey's vision [10] of emphasizing the learner's experience, which has inspired hands-on museums and science centers, such as the Exploratorium in San Francisco, and hands-on learning with tangible user interfaces (TUIs). This work is a follow-up of [50] and the open question on how to assess informal learning through casual interactions with a tangible music interface. It is also informed by the work around the National Science Foundation-funded project EarSketch [16] and their educational perspective of teaching coding concepts by making music with a low entry level using music samples. This approach aligns with Science, Technology, Engineering, Art and Math (STEAM) [29] education by incorporating the arts when learning STEM fields. Drawing from our experiences with TuneTable at MODA, we aim to contribute to the current discourse surrounding methodologies within the arts and maker culture. Of particular interest to us is the use of participatory workshops and interviews. Here we present our preliminary findings of the hands-on, informal learning process undertaken by young visitors when engaging with tangible music coding.

BACKGROUND

Learning Computer Science and Music

There is a tradition of teaching programming by means of music. An early example is the generation of music programs written in the LOGO programming language [5]. More recent examples span a wide range, from teaching computational concepts through musical live coding practices using Scratch [44]; teaching computing concepts through Sonic Pi, a specific musical live coding environment that runs on the Raspberry Pi [1]; teaching both computer science (CS) and computer music concepts using Processing [33]; teaching how to program with Python by manipulating media content, such as sound [19]; to teaching computer programming concepts for building computer music applications and algorithmic compositions using JythonMusic [31]. Our research is mainly inspired by EarSketch [16], which promotes teaching computer science concepts by making music via writing code in either JavaScript or Python or by dragging and editing blocks in Blockly language [30]; and through the use of music samples from an extensive collection.

Tangible Play and Learning in Museums

Hands-on education was first explored by Montessori [35] and Fröbel [17] and later in the CS domain by Papert [38]. Play is an important component of learning [11]. A range of science centers promote playful experiences for learning STEM concepts, such as the Exploratorium [2]. There is a small but growing body of research that assesses and accounts for visitor learning during short-term, informal interactions (e.g., [21]), but we know little about how visitors learn computational thinking concepts through such experiences.

Tangible user interfaces (TUIs) is a broad term that refers to the design of physical artifacts that represent and control digital information. TUIs include a wide range of interfaces [15, 39]. The benefits of learning with tangible technologies have been presented by [37]. For example, Zuckerman et al. [51] explored digital Montessori-inspired Manipulatives, also known as MiMs, and endorsed their suitability for hands-on learning and group work. As a subgroup of TUIs, interactive tabletops have been reported as suitable environments for collaborative learning [20]. There are a number of systems and studies based on TUIs for music performance in public settings of which some are tabletop-based (e.g., Composition of the Table [24], the Jam'O Drum [7] or the Reactable [26]). Computational thinking practices are less explicit in these TUIs because they focus on facilitating music creation. We argue the need to make computational concepts more explicit in alignment with tangible programming [15, 18, 22]. Tangible programming for children has been investigated in public settings [15], in particular, a TUI for children was used to promote learning to code at the Boston Museum of Science [22]. There is little research to our knowledge on tabletop TUIs for music and STEAM education in informal settings, an area in which this paper contributes.

TUNETABLE: LEARNING TO CODE BY MAKING MUSIC

TuneTable[1] is an ongoing tabletop prototype that expanded EarSketch concepts onto a multi-touch tabletop with tangible programming blocks. It has been developed using open source technologies. Inspired by Reactable's [26] tabletop design, there is a lower infrared camera dedicated to the identification of tangible objects placed on the table using the computer vision software reacTIVision [27], which recognizes a set of symbols known as fiducials. There is also a projector in the base of the table, designed to provide real-time visual feedback to interactors via Processing [40]. The TuneTable project started in 2014 as a group graduate design project in co-author Magerko's Digital Media studio course at Georgia Tech and has been developed over three subsequent semesters.

Programming Language for TuneTable

The programming language syntax went through several iterations, informed by both informal observations of users and weekly project team discussions. The music performance software of Reactable [26] influenced this work, as well as the graphical representations of sound compositions in [43]. TuneTable was also inspired by the tangible programming language developed in [22] and the tangible representations of the musical instrument Tangible Sequencer.[2] Both TUIs keep a balance between simplicity in language and, respectively, computationally or musically interesting results. The overall aim of TuneTable was to develop a simple language that should make visible programming concepts by means of making music. It differentiates from the previous two examples in that it uses a standalone tabletop interface, which affords collaboration; and that it explores computational concepts applied to music making.

Users compose algorithmically using hand-sized acrylic blocks that can be placed on the table. There are 7 types of building blocks, including 1 controller, 2 sound generators,

[1]The code is publicly available at https://github.com/mbhuet/TuneTable (accessed July 25, 2016).

[2]http://www.tangiblesequencer.com (accessed July 25, 2016).

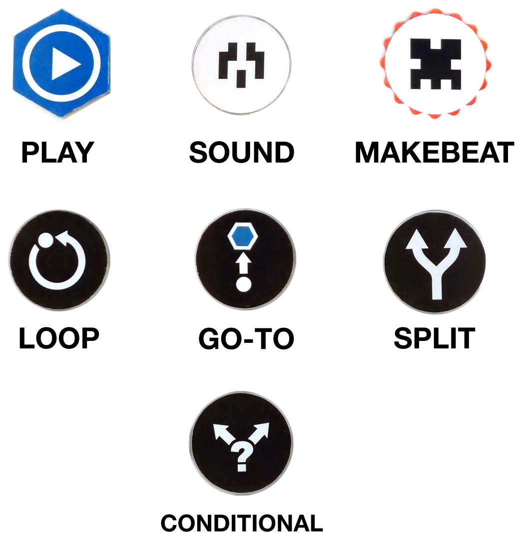

Figure 1. An example for each of the 7 types of tangible programming blocks.

and 4 functions, which are shown in Figure 1. There is a collection of 29 blocks in the version used for this study. It is possible to create both parallel and sequential connections between them. A visual flow path is projected in real time for each of the existing sequences of interconnected blocks, building a colored trail through each connected sequence. The data flow of the sounds that are playing is also indicated in real time, in alignment with Bret Victor's recommendations on learnable programming [47]. Paths that are inactive are colored in grey. For each new object placed on the table, a dashed footprint for a new object is projected, guiding and encouraging users to expand their compositions. See Figure 2 for an example of a musical sequence. Next, we describe each of the types of blocks.

- `play()` block (red, green, blue): This object is a controller and defines the start of a sequence of at least one sound. It has a hexagonal shape. The color of the flow path is defined by the color of the *play()* block. A projected play button next to the block can be touched to start the sequence. If touched, the sequence starts and a stop button replaces the play button so that the sequence can be stopped at any time. When the sequence reaches the end (the last block in the signal chain), the play button is projected again so that the sequence can be started again. There are 3 *play()* blocks.

- `sound()` block: This object is a sound generator that contains three different music samples. The sample can be switched by tapping on one of three buttons generated around the block, numbered 1–3. It has a circular shape. The current selection of sounds is drawn from the chiptune sample bank developed for EarSketch by the electronic musician Richard Devine. This particular style of music was chosen after several rounds of feedback from users, the majority of whom enjoyed the "gaming" quality of the 8-bit sounds over more traditional rock samples and ambient tracks. All sounds are in sync. There are 14 sound blocks.

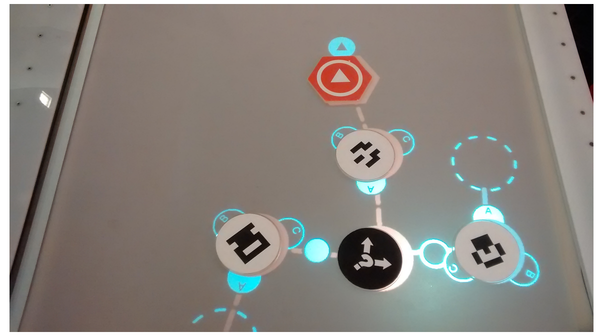

Figure 2. A sequence of tangible blocks with, from top to bottom, and following the order of the sequence, a *play()* block, a *sound()* block, a *conditional()* block and two *sound()* blocks.

- `makeBeat()` block: This object is a sound generator of sample rhythm patterns similar to the *makeBeat()* function in EarSketch. It has a gear shape to be distinguished from sound blocks. There are 3 different *makeBeat()* blocks for a 4-, 8- and 16-beat patterns, respectively. This is the only block that can produce sound independent from the *play()* block and encourage users to tap inside the indented areas to build their own custom rhythmic sequences.

- `loop()` block: This block is a function that spawns a projected, self-contained looping path, inside which additional sound blocks can be added. It has a circular shape. The more sound blocks are added, the bigger the looping path becomes. A projected number next to the block with plus and minus buttons can set the number of loops, which works by counting down to zero. There are 2 *loop()* blocks.

- `go-to()` block (red, green, blue): This block represents a function, pointing the flow path to the play button associated with its own color (a red *go-to()* block points to the red *play()* block, and so on). It has a circular shape. This block allows users to "jump" between sequences, building more complex compositions and enabling collaborations between individuals and groups working on the table at the same time. There are 3 *go-to()* blocks.

- `split()` block: This block splits the signal into two paths running in parallel. It has a circular shape. There are 2 *split()* blocks.

- `conditional()` block: This block creates a binary path that allows the user to switch between two possible branches on a sequence chain. It has a circular shape. There are 2 *conditional()* blocks.

Physical Design

The physical design of the table has been adapted to a museum setting and to the activity of casual making music in collaboration. This table was originally developed by [49] and used in [32]. We decided to incorporate a set of transparent orange acrylic panels allowing visitors to see what is behind the scenes of the table. We replaced small wheels attached to the table with larger, more robust wheels for easy mobility. We implemented a storage system for the blocks to avoid stacking

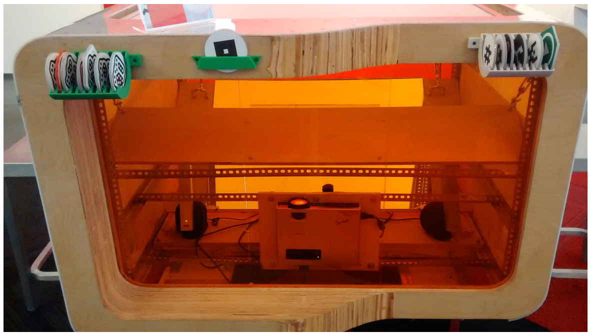

Figure 3. Close-up of the TuneTable.

them on the edges of the table. These mountable block holders, designed and printed through 3D modeling, are placed in a trough-like style at the corners of the table, providing space for users and evoking the experience of selecting vinyl at a jukebox. We also added custom mounting brackets to hold separately preferred blocks. We wanted to ensure that blocks were easy to access from multiple sides of the table, were easy to see, did not interfere with visitors' interactions, and saved space in an organized way. Figure 3 shows a close-up of these elements.

As for the icons representing the sounds, we drew inspiration from the video game *Space Invaders*, which aligns with the chiptune sounds. We developed a black and white customized block icon generator with Processing. We selected the set of icons by making sure that the images were distinct enough from one another, and that they could be individually identified. As for the icons representing the functions, we chose metaphors that were simple and clear, mostly using arrows, basic symbols and colors for the *go-to()* and *play()* blocks.

STUDY DESIGN

Research Questions

Our overarching research question is whether or not, and how, children and teenagers can informally gain content knowledge in and positive attitudes towards computing through experience and ownership in public settings. The focus remains on how to facilitate informal learning through casual interactions and how to assess to what extent children and teenagers learn from them. In particular, we are interested in a preliminary insight on: (1) how can we assess informal and hands-on learning of music and code in an open form; (2) to what extent teaching the technology behind the scenes of the artifact can help to learn music and coding concepts; (3) to what extent a participatory and experiential design approach in informal learning can help users feel ownership; and (4) to what extent an interactive tabletop is useful to promote this educational approach.

Setting

The Museum of Design Atlanta[3] (MODA) is a museum located in Atlanta, Georgia, devoted exclusively to design. MODA's mission is to advance the understanding and appreciation of design as the convergence of creativity and functionality through exhibitions, education, and programming for visitors of all ages.

As a precursor to the study, a collaboration between MODA and the TuneTable team informally started in Spring 2016. We observed two of their in-house workshops of 1.5 hours duration each to get a sense of their teaching approach: a hands-on workshop on Arduino with 4 children and a hands-on workshop on littleBits [6] and LEGO with 2 children aged 6–7 years old. This provided us with valuable knowledge not only regarding the demographics of current MODA patrons, but an inside look into how they structure, prepare for, and run kid-centric technology-based workshops. Workshops at MODA are carefully prepared by co-author Drozda, a design thinking and innovation educator who develops interdisciplinary programs that combine cutting-edge STEAM tools with the design process. Her emphasis on exploratory learning serves to emphasize the learning process rather than an end result, encouraging self-motivation and confidence in the kids themselves. Beyond the classroom, she also works to incentivize kids to continue work at home, and on occasion she conducts informal "mini-interviews" through social media.

Teaching practices at MODA are inspired by hands-on and experiential education. They resonate with project based learning [28], and a minimal intervention in education, such as the experiment of the Hole-in-the-Wall in India [34]. The TuneTable is located in the lobby area at MODA, with the aim at inviting patrons to freely interact with and learn from the table, similar to the Hole-in-the-Wall experiment. In MODA, ownership is a key term that refers to the mastery of the material, a desire to continue to self-learn and build upon that, and the desire to teach others. Thus, it represents a successful interaction with an exhibit, and by extension a fruitful visit to the museum. Here we investigate the nature of ownership and experience within a tangible and tabletop environment.

Participants

We conducted observations of two school field trips. In the first school field trip, there were about 20 campers, who ranged in age from 11–16 years old and came with 2 adult chaperones/teachers. Some of the students and chaperones participated in the workshop. There was a fairly even balance of girls and boys. In the second school field trip, there were 24 campers divided into 4 groups who came with 10 adult chaperones/teachers. The ages ranged 8–14 years old. From here on, F1-G1 refers to the group of the first field trip, whilst F2-G1 up to F2-G4 refer to the four groups of the second field trip.

Procedure

The two field trips were 1.5 hours divided into two parts of forty-five minutes: an interactive, guided tour of the current exhibition and a hands-on design activity in the lobby/design bar area of MODA that promotes comprehension and practice of the design process. The difference between school field trips and in-house workshops is that in the former there is less time for the hands-on activity and the number of patrons is

[3]http://www.museumofdesign.org (accessed July 25, 2016).

larger. Moreover, in field trips there are chaperones who can engage with the activity. In the in-house workshops, instead, parents are invited to engage with the activity at the end so that children celebrate their achievements with them. The hands-on design activity was on the TuneTable. The activity was a challenge: creating an audiovisual piece for a music album.

During the TuneTable activity, the artifact was introduced as a collaborative work between Georgia Institute of Technology (Georgia Tech) and MODA. In F1-G1, campers were invited to learn about both the TuneTable and EarSketch. Tutorials were kept informal and campers were encouraged to jump in to the two activities as they wanted. In the second field trip, the 4 groups were introduced to the TuneTable with more detail, including hardware, software, and the blocks. Campers were exposed to the topic of design process by discussing that the TuneTable is a musical instrument with an open-ended design. Moreover, it was discussed as a prototype to teach coding and computational music in an innovative way, establishing connections with the current exhibit on wearable technology. For example, the reacTIVision software was explained as how it sees and reacts to the fiducials on the blocks. Fiducials were compared with barcodes and with the QR codes that the Oculus Rift in the wearable technology exhibition uses for augmented reality. Processing was also introduced more briefly, which was run in front of the students. Students were familiar with Blockly and Scratch with regard to programming experience. The TuneTable blocks were also introduced, e.g., the 3 *makeBeat()* blocks, the 3 *play()* blocks and the 3 *go-to()* blocks. Often the *loop()* block was introduced as similar to block coding. Computer science aspects of the table and its functions were also explained by comparing it to different Scratch blocks. Then students were encouraged to explore themselves the different blocks. Finally, the groups created a piece together.

Data Collection

We collected data in the wild [42], as opposed to lab studies. The facilitator of the activity recorded video snippets of the group's interactions using a handheld mobile phone. The role of the facilitator is a trade-off between adapting an action research approach of intervening in the scene [41] and minimal intervention. This approach is suitable for such an early stage of research to help visitors think aloud during their casual interactions. The videos were captured focusing on patrons' hands interacting with the blocks. This approach excludes the observations of eye-contact and face-to-face behavior, which can be useful in later stages of this research. In the case of EarSketch, only the screens of the computers were recorded. After fifteen to twenty minutes, students tended to show to chaperones/teachers their piece and ease back from the table. If they did so sooner, the facilitator walked over and asked questions to provoke them to inquiry about their composition. The enquiries were video recorded, as well as the piece playing and a final reflection about it. This recording approach is termed *maker interviews* and has been used extensively by co-author Drozda for teaching LEGOs, littleBits, or Minecraft [46], among others. The video is used as a way to making reflection fun and to show that designing with this technology is worth a video. It also aligns with the use of social media, which is commonly experienced by patrons in their everyday life. The questions are open-ended and try to support complex imaginative play.

Data Analysis

We had informal discussions between the first four authors before, during, and after data collection. Our discussions were about visitors' behaviors around the table with a focus on the videos from the field trips. We identified and iterated over 4 emerging themes related to the research questions and workshop experiences:

1. *Ownership of failure*: It refers to how failure is faced during the learning process of computational concepts on a tabletop interface, and whether self-learners can maintain motivation to seek solutions and continue self-education through failure.
2. *Ownership through collaboration*: It refers to the impact of tabletop collaboration to the sense of ownership of computational concepts. It also embraces a sense of shared ownership, a term that refers to the group acquiring mastery of the material.
3. *Ownership of the design*: It refers to the satisfaction in the music composition as the first step in participating in the design process of the tabletop interface. It indicates the ability to transfer knowledge to other uses of design and the design thinking process coming from multiple exposures of creating.
4. *Ownership of code*: It refers to the understanding of computational concepts on a tabletop interface.

FINDINGS

The MODA educators recorded 13 video snippets of the first field trip, and 14 video snippets of the second field trip. The videos captured different moments of the activity, from initial exploration of the table, to the creation of the audiovisual piece, to the reflection on it with maker interviews. The group F1-G1 was late. Thus, a single huge group was asked to create an audiovisual piece together due to the time constraints. In F2, campers were divided into 4 groups and each created an audiovisual piece. G4 was formed as a mixture of girls from previous groups. Each group spent about twenty minutes with the table for experiential play and learning.

EarSketch vs. TuneTable

In F1-G1, the EarSketch group consisted of one girl and four boys, whilst TuneTable was used by a larger group of 6 to 8 campers. There were five laptops open to EarSketch (see Fig. 4) and an additional computer with a projection of the web application, which was controlled by the educator. The two teams worked for about 20 minutes. Most of the EarSketch team had prior coding experience. The difference between the EarSketch and the TuneTable's experience is that in the former, campers had a larger sound palette to explore (e.g., dubstep samples). For example, a boy sat down at EarSketch and spent a long time exploring the dubstep samples, whilst another boy was experimenting with rhythm and beats. In

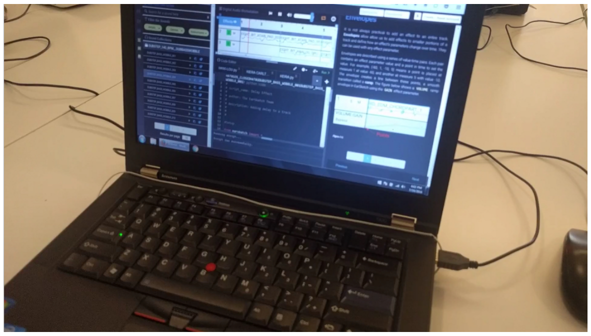

Figure 4. A laptop with EarSketch at MODA.

Figure 5. A group creating an audiovisual piece with the TuneTable using 3 *play()* blocks, 2 *go-to()* blocks, a *conditional()* block, a *split()* block, and 14 *sound()* blocks.

the TuneTable, instead, campers worked with the given subset of sounds provided by the tangible objects. Another prominent difference was the way of coding: in EarSketch campers typed the code (they worked with the scripted version of EarSketch), whereas coding in the TuneTable was through the use of physical blocks. This more individualized experience with EarSketch was visible when, for example, a girl who was working with a computer had the opportunity to collaborate with a MODA intern who has some Javascript experience. This one-to-one interaction helped her to get further in coding during the short amount of time. TuneTable was found to be easier to operate, and the tangible blocks were introduced to the groups by comparing them to Blockly, which they already had exposure to. Our future intent is to support transfer knowledge from TuneTable in the museum to EarSketch at the school or at home, however the duration of the study did not allow us to do that yet. This comparison between the two platforms helped us to start exploring the different affordances of each platform and the potential challenges we might face when transferring from one platform to the other.

Coding Errors in TuneTable

It was difficult to tell whether campers were understanding the error messages with the table. In a number of occasions, there were many blocks on the table, of which a number of them were unused. Based on how campers moved the blocks on the table, it seemed that they often thought that the blocks were being used. For example, a common error was to combine the play button with the *makeBeat()*, not realizing that this combination was not working. Sometimes the sound blocks were having difficulty in staying connected due to momentarily recognition issues with the computer vision engine. However, we noticed that the campers did not try rearranging them to straighten their connected visual flow path.

Even though campers were introduced to the different types of tangible blocks, it is unclear from the videos whether groups were understanding the computational concepts, such as *loop()*, *conditional()*, *split()*, or *go-to()*'s, because they were either not used or they were disconnected from other blocks on the table. For example, F2-G1 did not investigate why the loop was not working and shifted to exploring other blocks.

Designing and Listening to the Audiovisual Pieces

Teaching what technologies are behind the scenes of the table proved to be useful for campers to be more critical with their achievements. In particular, campers were critical with the sounds produced. For F2-G1, the sounds were like "an annoying video game", or "just really glitchy". However, the criticism was on the sound design and sound outcome, as opposed to the design of the tangible representations of computational concepts or the visual feedback.

Each audiovisual piece varied in complexity. The configurations ranged from basic configurations, such as not using functions (F2-G2); to using a few functions, such as *makebeat()* and *loop()* in case of F2-G1; to using a range of functions, such as *conditional()*, *split()*, and *go-to()*'s in case of F2-G3 (see Fig. 5).

There was a clear distinction between the design process of the piece vs. the performance of the piece, between building and listening. Both were quite collaborative in nature. In the presentation of the piece, there were a number of synchronized actions. For example, often campers coordinated on hitting play buttons and synchronizing other activations during the piece, such as F2-G3, in which they coordinated to touch the *play()* block in sync for a synchronized start; or F2-G2, in which three different people worked to make the play button run. However, at the same time, the interaction was little once the configuration of the piece was defined. This was closer to a listening activity, as opposed to a performance activity. Group members were staring at the table, listening to the music composition. "Don't touch it!" said a camper from F2-G2. In F2-G4, some of the campers were even dancing when listening to their piece.

The facilitator celebrated perseverance with the compositions, as MODA generally does with the different aspects of the design process. From the maker interviews, it is hard to tell whether campers were learning computational concepts, which informs us about what we need to consider in future research. The facilitator challenged the groups if they looked stuck. For example, in F2-G1, she challenged the campers to try more than one *play()* block.

Collaboration in TuneTable

Collaboration happened in many ways. The groups worked in collaboration during the design process of the piece. For example, F1-G1 decided in team what sounds worked best. The groups also collaborated when performing the piece, as discussed in the previous section. Groups also collaborated on composing and solving problems. For example, F2-G2 had two blocks that were glitching because they were placed very closed together. As a team, they decided to line the sounds up so they linked the blocks again and solved the glitching. We also identified different group dynamics. For example, F2-G2 was mostly run by older girls who were telling another girl not to place blocks in a certain way.

In the museum, ownership happens if patrons retain any interest on the topic. It is related to persistence of work, to when people come back and want to work more on a topic. Field trips were mostly rushed so it is difficult to tell whether visitors took long-term ownership. However, we observed that some of them did take short-term ownership of certain aspects, e.g., when sharing what they learned between them.

DISCUSSION

Next, we discuss four preliminary levels of ownership that we observed in the field trips and that inform our future work: *ownership of failure*, *ownership through collaboration*, *ownership of the design*, and *ownership of code*.

Ownership of Failure

Failing is part of the learning process. Solving errors in the code is part of learning to program, yet it is less obvious how to tackle error handling on a tabletop interface. Moreover, in informal learning there is little time for working on errors or 'debugging'. An open question is how to strengthen the relationship between error handling and failure in a tabletop environment in informal learning; in particular, how to embrace error handling processes in short-term tabletop interaction, so that students are able to identify programming errors, are motivated to solve them, and solve them within a short time scale. Another open question is how to promote ownership of failure and successes built on persisting through mistakes within a tabletop environment. Making the errors visible as part of the TUI contrasts with the tangible programming language proposed by [22], a physical jigsaw puzzle in which it is very difficult to produce a syntax error.

When campers were asked about their understanding of errors that they created or learned from, the focus often turned to the functionality of the TuneTable itself. Students usually pointed out sounds they liked or disliked and potential table glitches. Even with more leading questions from the facilitator, ownership of trial and error learning did not seem readily embraced. A potential approach is to be more explicit about the errors in code as part of the learning process and their manifestation in the table. For example, letting the students know that errors in the tangible programming language will inhibit a program from running properly, and asking them awareness questions about whether, for example, every block on the table is connected. In the next design iteration of the table we will consider how to make more visible the error messages for unused blocks in a standalone format, as opposed to use the help of a facilitator.

Ownership through Collaboration

Discovery and knowledge transfer happened in collaboration, in alignment with project based learning [28]. For example, understanding how the blocks work or creating a piece together. This indicates the suitability of a tabletop interface for informal learning in museum settings, as already pointed out by [12, 50]. Even though collaboration was generally egalitarian between campers, there were also less egalitarian situations. It is unclear to what extent the facilitator should intervene in unequal group dynamics. The effect of an intervention is that it can inhibit the creative flow of the group. In addition, facilitators often have to consider chaperone/teacher involvement in teaching, which can affect the facilitator's intervention. MODA facilitators may find themselves collaborating with the chaperones, similar to the second field trip, or teaching alone as in the first field trip. Collaboration in informal learning is essential, which includes both peer-to-peer learning and learning from chaperones/facilitators. A little level of intervention from the facilitator promotes peer-to-peer learning, yet it is an open question how to best intervene when students are stuck or seem to not understand the computational concepts. A potential approach to addressing these collaboration challenges is discussed in [13] as a longer-term peer-to-peer collaboration, which should be adapted to shorter-term and in-the-wild collaborations. Future work should address how the table can support multiple perspectives of collaboration, both with and without a facilitator's intervention.

Ownership of the Design

Presenting the table as an iterative prototype design, and learning how the table works, promoted critical thinking among campers about the design process. Yet, the design of the table is still fixed. For example, a useful feature would be the ability to customize the sounds from the large EarSketch database, so that students can work with sounds of their choice. We noticed more interest on critiquing the table in the second field trip, in which there was a better understanding of how the eye of the table, i.e., camera and computer vision engine, works. The ownership of the design process as a tool aligns with participatory design [45], STEAM education [29] and project based learning [28] applied to informal learning in a museum setting.

During the creation of the final piece, compositions of the groups went through iterations, and a reflection process was raised by facilitator's questions to students about their design decisions. The maker interviews proved to be useful as an open form of inquiry and reflection, similar to the research methods used in the digital arts [25] and the maker culture. It seems that one of the key roles of a facilitator is precisely to help students to learn about critical thinking, and that a tabletop can be a suitable platform to learn about it. This knowledge can in turn be transferred to other design fields and media. At this stage, however, it is an open question how to make patrons reflect critically on their artistic work from tabletop interactions, with no intervention from a facilitator.

Ownership of Code

As previously discussed, there is a tension between the level of intervention of the facilitator and the group dynamics with their own pace of learning. Ownership is related to the understanding of the concepts, and time can be a factor. It is thus still an open question how to effectively deliver computational concepts within a 20-minute session in a self-contained and modular style. Students who have come back to the TuneTable are visibly more consistent with their interactions and take clearer ownership than students who do not come back. This became apparent through the videos and arguably it can be solved with a more explicit intentionality from the facilitator and signage. For example, showing a display describing the seven building blocks of the tangible programming language, and adding teasers with questions such as "Do you know that you are coding?" or "TuneTable is designed to teach coding" can be helpful. The silence of the table when nobody plays and from people who stored the blocks in the storage area and left, could be also a preventing factor.

It is important to think about how to raise motivation and increase intention to persist in computing beyond learning small snippets of code within short-term interactions. Both the educator and the interactive system should promote this approach. In the case of MODA, with a variety of design activities available to visitors, educators often encourage students to follow their interests. This style is influenced from multi-sensory learning centers, as well as the Reggio Emilia approach [14]. Design provocations are intended to be positive introductions to the subject matter. Educators are mindful that a negative experience with EarSketch, for instance, might lead to a distaste for coding. A pedagogical challenge is how to teach coding in alignment with educational principles of informal learning in public settings. For example, clearer connections could be made more visible between TuneTable and EarSketch by comparing Blockly code (as opposed to the script code) and tangible programming. However, arguably, using Blockly with older campers than fifth graders can be less inspiring as they perhaps prefer to work with scripting programming languages that they already know.

In order to support and motivate self-learning and ownership among students in informal learning, technologies need to be known, accessible and free. A successful example of ownership of code are the MODA Minecraft workshops led by co-author Drozda, in which students are passionate about Minecraft and start circuitry and learn syntax that is similar to Python or Java. Another successful example is the story of the challenge with the 3D printer Tinkercad. Drozda led numerous field trip tutorials that introduced the open-source, browser-based CAD program, Tinkercad, and gave a challenge that any student who created an original 3D model in Tinkercad could have the model printed by MODA. Although this challenge was presented to numerous groups, only one student completed it. The student learned it first through MODA, but it was then re-enforced in school, which was probably a key factor to the student's progress. This example indicates that trajectories from school to museums can promote self-learning and ownership in informal learning contexts. However, an emerging challenge is to motivate students with new, less popular educational platforms operated with code that are accessible within short-term interactions, and to support longer-term interactions from these experiences.

CONCLUSION AND FUTURE WORK

In this paper we introduced the design of the TuneTable system, a musical tabletop for learning tangible programming through music, and presented its initial assessment at MODA. We explored whether informal learning can occur through experience and ownership, and identified four related themes: *ownership of failure*, *ownership through collaboration*, *ownership of the design*, and *ownership of code*. Although in-the-wild research can be more risky, we discovered that short video snippets, and in particular, maker interviews led by the facilitator of the activity, are a helpful tool for scanning informal learning of music and code adapted to each group dynamics. At this stage, it was useful that the programming activities were open and flexible. Future work includes comparing this methodological approach with other reflective techniques, e.g., concurrent or retrospective, in terms of noisiness.

We investigated the benefits of teaching how the table works to students by participatory and experiential design, and found that they can become more critical. However, some computing processes need to be more visible from a pedagogical design perspective, such as error messages and error processes. Future research points to exploring how to deal with error messages in a tangible programming language. Also, we discovered that the tabletop promoted hands-on collaboration. However, computational concepts were hardly explicitly discussed. Future work includes developing best practices on how to teach and inquire students about computational concepts. Also next steps include exploring how to incentive patrons to come by themselves with no intervention of the museum's facilitators. This would include visible signage and teasers. In addition, the assessment of participatory workshops and maker interviews should be adapted to more open self-learning.

Finally, we pointed directions on how to better support ownership of computational concepts in tangible programming. This aims at promoting not only self-learning experiences at the museum, but also trajectories between the museum and the school or home. We should think technologies and props to support self-learning beyond the museum experience, so that it can have impact at a longer term. In particular, a better link between the TuneTable and EarSketch could be designed for supporting trajectories between the museum and the school or home. This could foster connections between groups online.

Overall, this paper showed a successful interdisciplinary collaboration between the museum and academia.

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