COMB – Shape as a Meaningful Element of Interaction.

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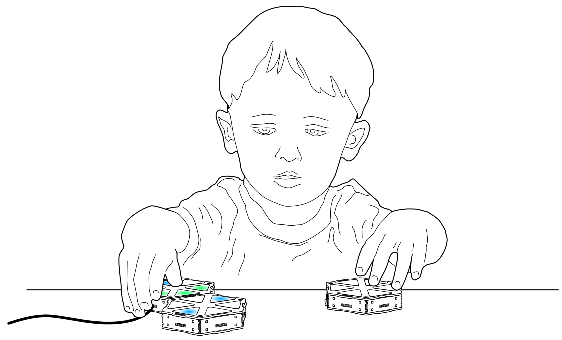

Figure 1. The tangible modular interface COMB enables children to practice electronic/digital music. By building structures from block-like modules children can access different digital instruments. These instruments can then be step-sequenced[1] to create rhythms beyond the otherwise approachable complexity.

ABSTRACT
This paper introduces a tangible user interface (TUI) concept designed for child-oriented musical interaction and education called COMB. The interaction concept of the interface is based upon the natural behavior and metaphors found in children's play during construction with building-blocks. This paradigm is used to increase the accessibility of the otherwise expert-focused digital and electronic music creation to children. We evaluated our prototype during two different study setups. We found preliminary indications that this concept fosters imitation during learning. Therefore, the usage of shape as a meaningful element of interaction could be a promising design strategy for interfaces addressing children in this domain. In this paper we present the theoretical foundation of the concept as well as technical details of the prototype. Furthermore, we discuss how this concept can be applied to increase accessibility of technology in various other domains.

Author Keywords
TUI; Modular; MIDI Sequencer; Children

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

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INTRODUCTION
With the ongoing development of smaller, more compact and cheaper electronics as well as the resulting new renaissance of analog and digital electronic instruments[2], the influence and relevance of electronic music for the main stream culture constantly increases. However, because their design mainly focuses on trained professionals, the use of those instruments by young children is difficult. This circumstance is due to human factor restrictions such as physical size and required skillfulness to operate hard- and software solutions correctly. Conceptual and cognitive hurdles are part of this restriction.

To address this shortcoming, we implemented an interface concept based on a modular interaction approach. Familiar and playful paradigms are integrated to support learning through imitation and to create an explorative and self-regulated experience. In this domain our research question resolves around the challenge on how to increase the accessibility of electronic music creation for children and if novel interaction concepts and design strategies can provide learning benefits in this domain. To answer this question, we used a research through design process [16] which was coined by experience prototyping and several iterations to generate profound insights during evaluation setups.

The paper is structured as follows: To frame our interface implementation we provide an overview of related work in the domains of: (a) learning theories and musical education (b) learning interfaces and expressive use plus (c) tangible interaction vs. organic user interface design principles and case studies. Next, we introduce the design space in which

[1] COMB video demonstration: https://vimeo.com/231299236

[2] http://msretailer.com/analog-synthesizer-renaissance/

we have placed our prototype concept, in order to position our work in relation to previous efforts and investigations. In the main section we exemplify the design process, technical details along with functional aspects. In the final parts of the paper we provide insights and a summary on two conducted user studies. We close with a reflection on benefits and limitations of our approach and discuss how it could be transferred and utilized in other domains.

In a previous publication we emphasized the practical utilization of the TUI concept for demonstration purposes at a conference series [3], this work is concerned with the conceptual framework, in-depth implementation details regarding hard- and software components as well as SMD layout and manufacturing processes. We further elaborate on insights gained during different study setups and summarize the contributions of our work as follows:

- We share detailed technical descriptions of our modular interface concept COMB which allows children to sequence digital instruments by constructive play. We further provide the necessary depth of detail in hard- and software components to replicate our approach.
- We outline an interaction vocabulary derived from a shape-centered interaction concept.
- We provide preliminary insights from two evaluation setups with a diverse user group (adults vs. children).

RELATED WORK

To differentiate COMB from established interfaces and research from the NIME community [4, 10, 31] we discuss related work that was mandatory to elaborate on the conceptual approach and further discuss projects that either use *shape as an input method* or block-like devices in combination with *constructive interaction*.

Learning Theories & Music Education

The key of an enjoyable and persistent learning experience is motivation. Thereby, two concepts are differentiated: intrinsic and extrinsic. The second describing external stimuli as found in punishment or reward and the first internal factors such as relevance or curiosity. Research has shown that extrinsic motivation can undermine successful learning on a long-term scale, because many persons stop performing once external stimuli are suspended. [22]. One key factor that can support or create long term intrinsic motivation is *curiosity*. During self-initiated and self-organized learning experiences knowledge gets constructed as described by Piaget's [2] theory of constructivism. This theory acknowledges the importance of play and exploration, performed by children with joy and persistence, which we found suitable for our design concept. *Exploration* can be considered a driving factor in persistent learning.

In summary, curiosity over exploration leads to *expression.* The creative use of the previously acquired knowledge represents an additional factor in learning [30]. Expressiveness can be found in play and creative activities in order to fertilize the transfer of knowledge as well as problem solving abilities. Further, the importance of *imitation* [14] as a key strategy of learning should be considered. Behaviors or patterns are constantly observed and reproduced by children. This not only applies to social behavior but also to technologies and practical knowledge in general [23]. The music pedagogues work of Carl Orff [8] and Zoltán Kodály [17] include the aforementioned key concepts for persistent learning. Both developed curricula and methods concerned with age-dependent tasks minimizing frustration and generating motivation to enable children's musical *expression*. This is achieved by reducing complexity of motor skills and music theory to lower the entry threshold and to create *curiosity*. Sturdy instruments are used to enable *explorative* access despite untrained operation. Learning units in this segment incorporate call and response and thus integrate *imitation* into the curriculum.

Interfaces for Learning and Expressive Use

Two disciplines are highlighted in the following section to show how shape-changing interfaces as well as constructive tasks are used to enrich interaction and foster learning regarding to curiosity, exploration, expression and imitation.

Organic User Interfaces: Shape as an Input Method

The vision of Organic User Interfaces (OUI) as described by Holman and Vertegaal [9] defines three key concepts, of which one proposes: function equals form. In OUI design function and form are an undividable unit. This idea is comparable to the concept of affordance described by Gibson [13]. The incorporation of this concept supports the user during the interaction process by revealing the way how to handle an interface. We drew upon this principle in our design approach and expressed it by communicating what is achievable by using it with shapes used as abstract representations of real-world objects. Other interface concepts utilizing principles of OUI design origin from the domain of shape changing interfaces [18, 20]. The game controller NinjaTrack by Katsumoto et al. [32] offers the user to perform modality changes by altering the shape and flexibility of the controller's structure. Reshaping the controller gives access to different functionalities related to the physical state of the interface. The main limitation of the concept is the interface's construction: It consists of small interlocked elements which restricts the deformability to bending around one axis and therefore the possible states the interface can take. The swarm interface (SUI) Zooids by Le Goc [24] utilizes a set of indistinguishable robots that can display information by their constellation as well as allowing the direct manipulation of the displayed data. Single elements still remain objects bounded to specific information and do not completely vanish into a mass of elements representing an object.

Tangible Programming: Construction as an Input Method

Beside shape as an input method construction is also utilized often as a central element of interaction. Many educational interfaces [26, 27] are based on this concept. This field of research is referred to as *tangible programming* and originated in the early 90s from the effort to give children access to programming languages. The approach behind those educational projects such as Algoblocks by Suzuki and Kato [12] is that modules represent instructions or code fragments or in general specific functions, thus children can explore programming without actually writing code. The same can be found in the platform littleBits by Ayah Bdeir [1], a project designed for developing electronic circuits without the need for soldering or wiring single electronic components. In this product, modules represent components of circuits; thus, children can learn about the synergy of sensors, actuators and signal-processors.

However, those interfaces don't utilize the concept of shape as an interaction element. Instead, they use function-related building blocks, where modules represent functions independent from context or situation. Typically, the interface's shape is just the result of the composition process. Multiple modules get combined based on their specific function and the intended overall functionality. However, functionalities can be achieved by following different approaches, resulting in different spatial configurations. Therefore, the abstract shape of the interface does not contain any information about the interface's functionality. In contrast objects created during constructive play, contain meaning although they are composed out of meaningless materials like clay, paper or building-blocks, a design concept that strongly influenced our approach.

DESIGN SPACE: STATIC VS. FLEXIBLE INTERFACES

To situate shape- and construction-centered interfaces in the context of this work we defined a design space to show manifestations of flexibility related to the interface's appearance and usage (see Figure 2).

This consideration is based on Vertegaal's and Poupyrev's [29] claim that future interfaces won't be limited to *static* shapes. Features of such *shape-changing* interfaces are: flexibility and variability. Where flexibility depicts temporary manipulations as bending, stretching or twisting and variability characterizes continuous transformations as folding or reshaping. Further, "constructive systems" according to Ullmer and Ishii [7] describe restructure-able or *modular* interfaces. Therefore, "flexibility of appearance" is threefold divided: static, shape-changing and modular. To picturize, we compare those states to the states of matter [24]. Here static relates to solid bodies, shape-changing to fluids and modular to gas. This emphasizes the idea of one continuous body, which gets softened until it splits up into its smallest possible components, that still form an interrelated and interconnected unit.

The dimension "flexibility of usage" is divided into two extremes: generic and specific. These originate from the distinction of TUIs and traditional interfaces (mouse, keyboard) [11]. However, a growing number of commercial interfaces incorporate concepts such as *personalization* or *adaptability*, where users arrange their own interface[3] to fit personal needs as ergonomics or interfaces are adaptable to different tasks by e.g. adding overlays[4]. Both cases bridge between specific and generic interfaces. Personalization closer relates to *specificness* since such interfaces are typically set up once, whereas adaptable interfaces constantly change based on the task.

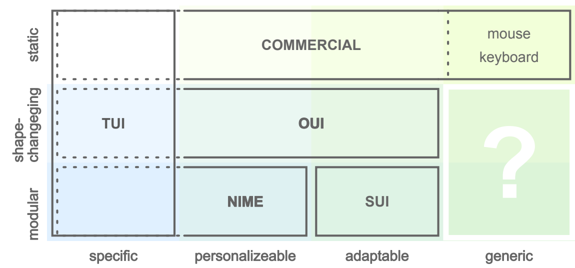

Figure 2. We visualize different HCI disciplines in this design space. Where generic use overlaps with shape-changing and modular characteristics space is opened up for the exploration of new design approaches. Here, COMB tries to fill this gap.

COMB – A DESIGN RATIONALE

As previously discussed, the specific problem we are addressing with our work is the inaccessibility of today's electronic/digital music for children. To bridge the gap and lower participation barriers in this domain we have designed a tangible interface and a corresponding interaction concept.

Design Process

Developing our experience prototypes [21] we followed an iterative user centered design process [15] that was informed by early validation sessions with the intended users in order to get the design right [5] (see Figure 3). To generate an enjoyable, usable and robust design solution for our design context we also had to overcome several technical issues that we´ll exemplify in the following section.

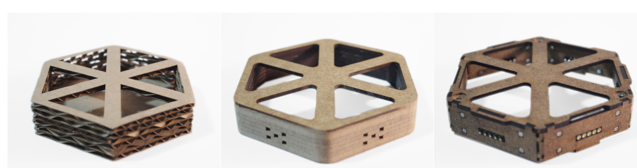

Figure 3. Several iterations of the housing have been done to define the size, most functional connector placement and a manufacturing process ensuring precise interconnections.

An Interface for Learning Music

To design a low-threshold and playful interaction we built on top of existing concepts and adapted those to the domain of musical education to facilitate immediate access based on applicable pre-knowledge. The most familiar and widespread concepts for children today are games and toys. Especially building blocks meet all the previously mentioned key learning concepts. Our conceptual interaction concept is based on the paradigm "what you see is what you get" (WYSIWYG), and constructed shapes resemble meaningful

[3] special-waves.com

[4] sensel.com

representations of real-world metaphors. The perceived meaning can be seen as the result of the constructed shape instead of as a consequence of specific block's interrelation.

To transfer this paradigm into a musical interface we assumed that shape representations could result in *musical meanings*. In our context musical meaning refers to different instruments. Children can build shapes associated with instruments to get control over these. Being in control could mean being able to play instruments in real time or in our case to compose musical patterns that are played and repeated automatically by the interface (see Figure 1). We opted for the second approach exposing a key concept of electronic/digital music: sequencing. This concept is used in hardware instruments as well as in music software since the 1960s [28] to program musical patterns. Further, this minimizes age as an exclusive factor by reducing experienced-based and practice-intense skills needed for real time operation such as recognizing rhythm or motor skills.

In summary, our interface concept enables children to sequence a multitude of instruments by playing with a modular block-like TUI (see Figure 1). The selection process of instruments is performed by restructuring the interface's shape, while each shape provides access to the associated instrument's musical pattern. Unmentioned shapes can be found through experimentation, motivated by curiosity. This concept enables musical learning and expression by adapting concepts of play which foster exploration as well as support visual comprehensibility and therefore imitation processes.

A Modular Tangible User Interface

Instead of using a continuous deformable material as, for example, clay within OUI design or function-related modular interfaces as used in tangible programming, we have chosen building-block-like modular elements conceptually linked to children's constructive play. We have implemented a *self-sensing* interface which can adapt to its constructed shape by representing specific information and providing access to different functionalities. Pictorially associations of form and function are used to support the learning process and stimulate imitation as well as experimentation. This can especially be valuable in educational disciplines to create motivation, interest and joy.

Our interface's elementary shape is based upon hexagons to enable stable geometric structures inspired by nature. Compared to quads, constellations of hexagons are hardly displaceable along their vertices. Further, structures derived from hexagons are not as artificial looking as structures derived from quads. Associations that occur are more nature-related such as insect eyes or honeyCOMBs, rather than tech-related (e.g. Tetris shapes). Such structures, called polyform represent all constellations serving as *valid* input shapes for constructive interfaces. Quad-based polyforms are called polyominos whereas hexagon-based ones are referred to as polyhexes. Less hexagon-based elements are required to offer greater variety in valid shapes [25].

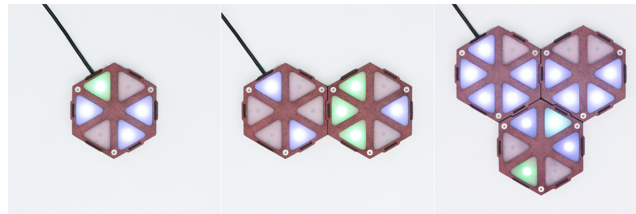

Figure 4. Each shape represents an instrument/-group. The single element controls a kick-drum, two modules provide access to percussive sounds (snare, claps, rim), the triangular shape represents the opened and closed high-hat.

Three polyhexes (see Figure 4) are implemented as valid shapes. This is currently restricted by the number of available modules. Each module contains six backlit silicone-pads which are used to provide access to rhythmical patterns comparable to other established step sequencers. Switching the accessible pattern is achieved by restructuring the arrangement of the interface's modules.

The Separation of Input Method

The assignment of shapes and functionalities aims at supporting the imitation of demonstrated and instructed interaction. Typically, one input method is used to perform multiple tasks as found in tablets, touchscreen-based devices or commercial midi-grid controllers[5], where changing functionalities/modes as well as controlling those are performed via touch input. COMB uses a one-to-one relationship between input method and task (see Figure 5). Thereby, the change of functionality is designed distinctly observable to support imitation. Children can easily repeat the main interaction concept and start exploring the interface on their own.

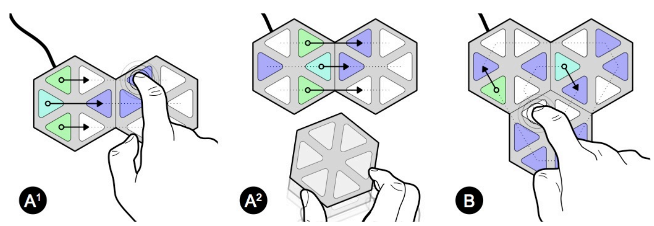

Figure 5. This figure shows the transition-phase between two functionalities/modes (A/B) as well as the main input methods. Tapping on the device triggers mode-dependent actions (A^1/B). Changing modes is achieved by restructuring the interface (A^2). Green/cyan lights show playback position and blue ones activated steps. Dotted lines indicate the spatial layout of each pattern whereas arrows point to the next playback position.

Interaction Vocabulary

Based on the idea of shapes representing instruments, two naïve design strategies of their relationship can be postulated: Shapes are modeled after real world instruments and shapes represent sound qualities.

[5] monome.org

Following the first approach, a round arrangement of the interface could symbolize a drum, whereas linear shapes could be associated with flutes or drum-sticks. These visual abstractions are low resolution representations and therefore support associations more than reassembling the real appearance of those instruments.

Based on the second approach aesthetic connections of sound and shape are used to define an abstract systematic. Mellow sounding tones such as sine waves relate to smoothly shaped constellations, whereas polygonal or chaotic structures represent harsh sounding or noisy instruments. This relation is even more abstract and focusses on emotional aspects, hence it can be compared to synesthetic where multiple sensations are mapped to each other and stimuli can be seen as complements of each other.

Both concepts cluster optical similarity and sound qualities. Therefore, users can forecast sound characteristics of unknown shapes based on their previously acquired knowledge. Thereby the possibility space gets organized and predictable. Both approaches are challenging in terms of abstraction. The emotional and personal perception of synesthetic makes it difficult to design and interpret such an interaction. Therefore, we integrated the idea of shape as a real-world representation in our concept.

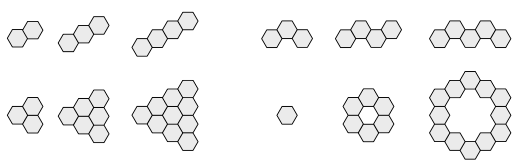

Figure 6. Different polyhexes can be grouped into families of shapes. Above we describe variations of: lines, waves, triangles and circles. Such families can represent related instruments.

Derived from this a system of shapes can be classified where similar appearing ones represent families of instruments (see Figure 6).

Target Group

Children have to meet these major requirements during the interaction with music software: cognitive skills to encounter the software's complexity and the ability to read to handle navigation through dialogues and menu structures. Beyond that, restrictions in hardware use are caused by lacking motor skills and the interface design's abstractness/complexity.

Therefore, we chose kindergarten children between the age of five to six as our target group, aiming to improve their access to digital/electronic music creation. They suffer from the above-mentioned restrictions but are cognitive more capable in handling complex tasks as younger children. Their cognitive capabilities as well as their scope of motor skills are further developed. Before the age of four, fine motor hand movements such as the tripod-grip are not used. Thus, complex building tasks, as needed during the operation of a constructive interface, are not part of their repertoire [6]. However, the span of four to six is too large to get comparable results caused by the developmental differences, as already five to six-year-olds differ in cognition and motor functions the typical one-year framing is used as a reasonable setting as found in common educational systems.

IMPLEMENTATION

To enable free and portable play our prototype should not depend on camera-tracking or other external technologies. Therefore, the implementation had to tackle the following challenges: quick and sturdy module-interconnections to facilitate construction, neighbor recognition and intercommunication to enable shape detection. Without external information the interface should recognize its current shape to adapt the displayed information as well as the available functionality.

Prototype: 1st Generation

The 1st generation prototype was concerned with refining the design in terms of reliability and usability as well as finding technical solutions for the envisioned interaction model. In the next section the development of the prototype is described as well as production techniques developed during the prototyping process.

Custom Prototyping Techniques

Custom magnetic connectors (see Figure 7) have been developed, to enable direct exchange of data and power between the modules during the prototyping and design process. Heat-shrink encloses the components and remains some of the magnet's flexibility. These custom connectors are suitable for purposes with the need for flexibility and therefore used as convenient tool for prototyping for example wearable devices. However, once such connectors are fixed in a rigid surface, they become vulnerable for bad contacts.

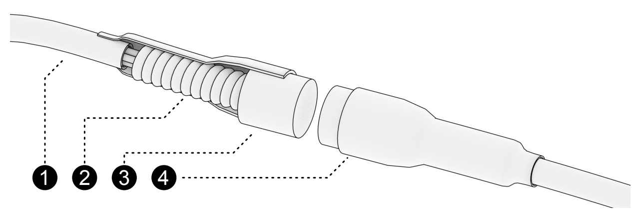

Figure 7. A four-parted structure has been used to overcome the loss of magnetic force caused by overheating magnets during soldering: (1) jumper wire, (2) ferromagnetic bridging-material (e.g. guitar strings), (3) magnet, (4) heat shrink.

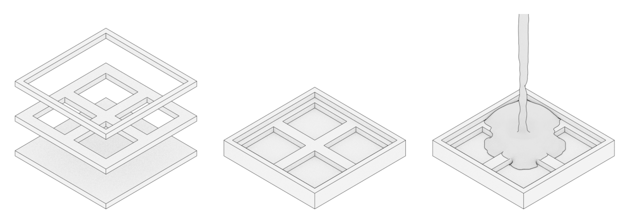

Figure 8. A laser-cut-mold for custom silicone-pads can be manufactured from three simple layers of MDF. The middle layer defines the shape and number of pads, whereas the bottom and top layer restrict the flow of silicone.

To manufacture uncommonly shaped silicone-pads, a simple workflow has been developed. Instead of 3D-printing or

CNC milling, laser-cutting has been used to produce custom molds (see Figure 8). This allowed us to perform quick iterations and adaptions during the prototyping process. Different materials can be used for the build depending on the desired surface texture such as acrylic glass or medium density fiber-board (MDF). To seal non-waterproof materials like MDF Vaseline has proven to be a cheap, simple and reliable solution: When applying heat, it penetrates the surface and makes the material hydrophobic.

Hardware

Each COMB module (see Figure 9) is constructed around the Teensy LC[6], a small footprint microcontroller. Features such as capacitive touch recognition and class compliant MIDI device capability are already included in the platform. For our needs its 32bit, 48MHz ARM Cortex-M0+ processor has been proven to be superior to most other microcontrollers with the same footprint and costs. As a class compliant MIDI device, it allows immediate usage on any computer with MIDI enabled software.

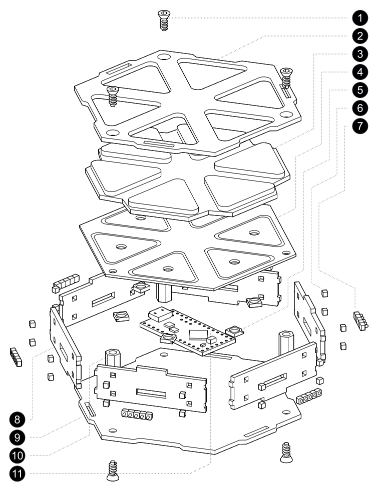

Figure 9. (1) screws, (2) top, (3) silicone-pad, (4) PCB, (5) WS2812b LEDs, (6) magnets, (7) spring loaded connectors, (8) flanks, (9) bottom, (10) spacer, (11) Teensy LC.

A handcrafted PCB which holds six LEDs on the bottom side as well as six copper pads on the top represents the module's core component. These copper areas can sense touch through the overlaying silicone-pads and contain holes to allow backlit illumination by the underlying LEDs. Through the silicone's deformability different intensities of pressure can be sensed and the WS2812b LEDs allow RGB feedback for each individual pad.

The module's hexagonal shape helps to reinforce the constructed structure. Further, tongues and groves as well as magnets are included into the design of the enclosure to define and hold the correct interconnections. Joints and screws ensure accessibility of the inner workings and therefore guarantee maintainability. Pogo pin connectors are integrated on all sides to distribute power (+5V, GND), transfer data between the connected modules via I²C (SDA, SCL) and enable shape-recognition via pulse-width modulation (PWM).

Shape Detection Algorithm

The shape recognition procedure consists of two major tasks: collecting the neighbor data from each module and from there reconstructing the current constructed shape.

The neighbor-recognition is performed via a basic pulse-width modulation signal. Each module is able to send and receive IDs via its middle pogo-pins. An ID represents the side index as well as the membership to a specific module. If neighbor information is requested the module stops sending and starts receiving. Once all sides are queried the module responds and restarts sending. This data is collected and further processed by the master module, which is constantly supplied with power through its USB connection.

By considering simple features basic shapes can be detected without analyzing absolute positioning of each individual module. The number and location of neighbors can distinguish circular, line-like as well as polygonal shapes. After identifying the shape, the absolute position and rotation of each module inside the shape is determined. The importance of known rotation per module is based in the translation of pad index to pattern step index. Based on an ideal orientation within a structure each pad can be referred to a specific step within the corresponding sequence. The pad ID has to be shifted depending on the module's rotation to match the step index. The other way around, information which is to be displayed, has to be processed to match the rotation of each individual module.

Newly connected modules have to be supplied with the current states of each of their pads depending on the displayed pattern. Changes in pattern and shapes have to be organized by the master module, which runs all sequencers.

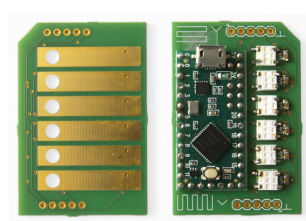

Figure 10. The prototype PCB shows that SMD parts are upside-down mountable which allows backlit-illumination through holes included in the PCB. Further, the possibility of the microcontroller SMD-style mounting has been proven to work seamlessly which reduces height requirements.

Prototype: 2nd Generation

To further increase reliability and to enable the production of larger scales, a 2nd generation prototype for testing purposes has been developed. This prototype focuses on the reduction of the design's complexity and the utilization of industrial

[6] Teensy LC: pjrc.com/teensy/teensyLC.html

production methods as PCB etching and CNC-milling or 3D-printing techniques.

To decrease production costs a single PCB two-layer design was targeted. This PCB contains: six touch-plates on the top-layer and footprints for the LEDs, the microcontroller, simple electronic components and the pogo-pin connecters on the bottom side. Resulting challenges are the upside-down positioning of the SMD LEDs as well as the SMD-like mounting of microcontrollers originally designed as through-hole parts to minimize space requirements. A prototype PCB was designed to verify the feasibility of those challenges. To reduce the hexagonal design's complexity and costs a rectangular design slightly larger than the microcontroller has been chosen. This prototyping iteration was performed to check if all requirements regarding further miniaturization and cost reduction are feasible (see Figure 10) and that thereby the mounting time could be drastically decreased.

OBSERVATIONS AND USER-STUDY

COMB has been presented during a large electronic art festival and was afterwards evaluated in a lab study focusing on the comparison to the commercial midi-controller Novation Launchpad (LP).

Field Study: Ars Electronica 2017

During the opening hours of the five-day electronic art festival over 40 demonstrations of the prototype per day have been performed: The visitors were introduced into the project's motivation, received a short introduction, had the possibility to experience the interface and gave informal oral feedback. In addition, 26 visitors participated in an AttrakDiff [19] evaluation after the demonstration.

In summary all participants were able to apply the interaction concept regardless of their age. In this setting most children started interacting without listening to the introduction whereas grownups depended on it as well as on the practical demonstration. We observed that some participants started with a wrong mental model of the interaction concept but were able to notice and correct it autonomously. Almost all participants tried unused shapes to look for unmentioned functionalities even if a large poster in front of them listed all valid shapes and the linked instruments.

Beside these observations the AttrakDiff survey has shown that the prototype generated high motivation among the users and has been received as highly usable during their first interaction. The interface was overall rated as: *desirable*.

Follow Up Field Study

To further investigate whether our prototype supports imitation we designed a within-subject lab study focusing on the detection of modality-changes performed with COMB and the commercial product Launchpad[7] (LP). The hypothesis we wanted to tackle in this experiment was: Shape is a more obvious representation of current functionality and is therefore easier to detect then conventional ones.

Study Design

Participants had to react to functionality-changes (see Figure 5) while watching video clips of performances on both interfaces. Those changes were either performed by restructuring the interface (COMB) or selecting buttons in a specific button-array (LP). Once an event occurred the study subjects were intended to operate a provided buzzer as quickly as possible. Shorter reaction times were treated as indicators for better observability and pin-point towards a better imitability. To define a base-line and verify the understanding of the task, participants had to react to changing categories of displayed instruments (guitars, pianos, trumpets) first. All three clips contained ten changes that were spread in the same time pattern over the 1:50 long video. The order of videos concerning the interfaces has been switched via a 2x2 Latin Square per subject to prevent learning effects.

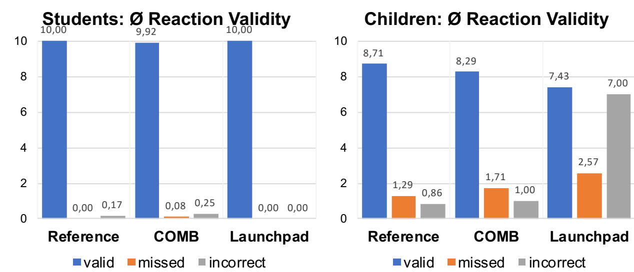

Figure 11. Students performed steadily during all three tests. Missed and incorrect reactions are negligible low on average. The children's performance differs clearly between conditions. An increase in missed events and a multiple of incorrect reactions have been recorded by LP compared to COMB.

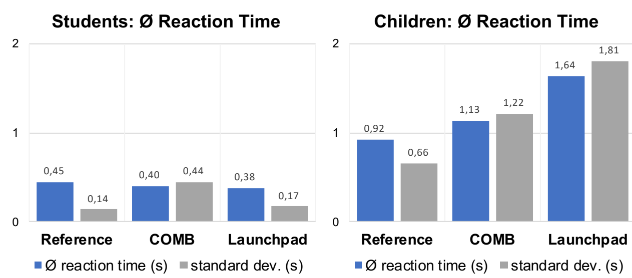

Figure 12. While students' performance remained more or less constant over the three tests, a clear increase in children's reaction time and its deviation could be observed.

Participants and Data Collection Methods

The study was conducted including seven children with an age ranging from five to six years (5,14) as well as 12 students with an age ranging from 19 to 28 years (23,22). Every participant was introduced to the topic and the study tasks before the screening of all three clips. Afterwards, participants were introduced to the operating principles of

[7] novationmusic.com/launchpad

COMB and had the chance to operate the interface on their own for a maximum of seven minutes. To collect feedback about the experience and initial impressions (first 7-minutes of use) a short semi-structured interview was conducted and recorded for later transcription.

Study Results

As shown by the reference test (Figure 11 and Figure 12) students as well as children were able to recognize the events and to react to those as expected. Further, students were able to detect all events correctly and reacted in a comparable timespan. We further observed that the student's reaction time's standard deviation received the highest value during the test of COMB. Children's performance decreased clearly over the three tests. We noticed an increase in *incorrect* reactions as well as a decrease of *valid* reactions. Also, the average reaction time as well as its standard deviation become worse when comparing COMB to LP.

DISCUSSION

The trial of unmentioned shapes as observed during both studies indicates the successful implementation of the design rationale's postulations as curiosity and exploration. Further, the ability to detect and correct false mental models can be seen as beneficial for self-regulated learning.

During the second field study an increase in preschooler's errors (missed and wrong reactions) as well as their average reaction time was recorded for LP compared to COMB. This indicates that functionality changes performed with COMB are easier to detect then with LP. These findings point towards a confirmation of the hypothesis that shape as an indicator of functionality can support imitation.

All demonstrations and studies proved the successful implementation of a robust and reliable technology setup. Our prototype allowed for fine as well as gross motor use. A consistent detection and low latency have been made possible by the implemented algorithm. Professional musicians claimed the hexagonal structure to be *counterintuitive* for common western music which is typically based on 4^{th} divisions. However, we can argue that all instruments influence the music one can be perform with and that restrictions in general fertilize a creative process.

Limitations

The high standard deviation of reaction times during the test with COMB and LP indicates the moment of change's higher inconclusiveness compared to the reference test.

The specific *moment of change* is blurred by foreshadowing elements as hand-position or finger gestures. Such additional hints allow reactions before the event and thus restrict the comparability of the average reaction times. Regardless of this, the comparability of error rates remains uninhibited.

Further, a student stated that he was not sure when exactly to react to those changes. Multiple moments were identified as relevant: the disconnection of blocks, the reconnection of blocks, the moment of the visualization's update. In contrast, with LP the distinct moment of pushing the button is equal to the moment of functionality change.

Both factors (foreshadowing and missing distinctness of changes) were not present in the reference study. The adaption of this explicitness can aim future studies on the comparability of reaction times. The focus on changes between still images could improve measurements.

Further Benefits of Shape as an Interaction Method

Considering the positive observations gained during our observations we consider potential tasks, where shape-centered user interfaces could provide benefits. The following categories were identified on the analysis of the current prototype, its evaluation and the collected feedback in both study settings. Further use cases are expected to be identified during future research.

- **Sequential tasks**: Activities such as video editing where the same distinguishable tasks are performed repeatedly but not simultaneously (cutting, color grading, sound editing, etc.). Switching between tasks could be performed by switching the interface's shape.
- **Collaborative tasks**: Collaboration could benefit from tasks represented by shape as the overview of other parallelized tasks could be improved. Further, co-working on the same task with the same interface could also benefit from shape as a meaningful element of interaction.
- **Tasks of adaptive complexity**: Individualized learning could be supported by the individual increase of available modules and shapes based on each child's learning state.

FUTURE WORK AND CONCLUSION

In this paper we have shown the implementation of shape as a meaningful element of interaction. We presented detailed descriptions of a prototype and the used technology that allows to use constructive shape-focused tasks to define its modes of function. In two evaluations we substantiated the usability und understandability of the concept across diverse age groups and found indications for such technologies being beneficial for kindergarten children. To further substantiate our research work on this topic in the near future we are aiming at:

- long-time studies in kindergartens
- expert evaluations in studio or live situations
- adaption of pre-attentive perception concepts to TUIs
- influence on holding function-states in working memory

A further goal of our research work is to provide free access to hard- and software components to enable designer and researchers to experiment with our concepts and develop them further or adapt them for their purposes.

We firmly believe that the investigation of shape-centered modular interfaces opens up new possibilities in the design of user interfaces that stimulate creative and persistent experiences. This familiar interaction can help to lower access thresholds as well as support visual understandability.

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