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Novelty-based cognitive processes in unstructured music-making settings in early childhood

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***Abstract*—Humans have the capacity to invent novel ideas and to create new artifacts that affect the surrounding environment. However, it is unclear how this capacity emerges and develops in biological systems. This paper presents an empirical study which investigates the development of novelty-based cognitive processes in the context of unstructured music-making activities in early childhood. We used principles of intuitive theories of emergence, the paradigm of overlapping waves of mechanisms of change and theories of music cognitive development to theoretically conceptualize the developmental process in the specific context. We applied the methodological principles of micro-genetic analysis for the development of an annotation scheme of micro-behaviors, which correspond to a set of cognitive processes. We took into consideration child's behavioral manifestations of music-induced affective engagement, as an indicator of intrinsic motivation. Our results suggest that the process of transition from spontaneous towards deliberate actions develops through exploratory actions, evaluation of the outcomes, reasoning and planning. The structure of these actions appears in the form of dynamic overlapping waves rather than in a linear or iterative manner. Additionally, our results indicate that children in early years make use of the affordances of the provided tools to scaffold their transition from concrete visual representation of sonic features towards abstract musical thinking, which suggests that musical development appears with the generative tension between action and symbol. Implications and future work are discussed regarding the development of intelligent robotic systems for user adaptive scaffolding of the observed mechanisms of change.**

***Index Terms*—Biological systems, intelligence, learning, development**

I. Introduction

The emergence and development of novelty-based cognitive processes are fundamental mechanisms for human evolution and appear throughout the human lifespan. In the case of early childhood, these cognitive mechanisms are dominant in the context of child's play activities in order to make sense of, successfully navigate into and creatively transform the surrounding world. It is with these mechanisms that children generate strategies that facilitate the construction and development of novel mental representations and schemata through unstructured playful activities. These activities are characterized by spontaneous and exploratory actions which gradually transform into organized and deliberate behavioural manifestations and contribute to the transition from sensori-motor to symbolic representations. However, the mechanisms of this transition are not clear yet, albeit sustained task-related interaction seems to be crucial.

The development of children's sustained task-related interaction has been associated with intrinsic motivation, which scaffolds children to reach and expand their developmental potential. Research, which is rooted in Dewey's theory of child's development [1], has shown that intrinsic motivation is supported by the generation of personal meaning through current - but not necessarily structured - activities [2], [3]. Intrinsic motivation has also been associated with task-related affective engagement [4] which is one of the fundamental elements of Papert's principles of constructionism.

Papert's principles have been widely used for the investigation of children's development through meaningful play activities in the context of mathematics education and computational thinking [5]. In the same line with Dewey and Papert, but in a different domain, Bamberger developed her theory for child's musical development, which utilizes the domain-specific characteristics of music-induced affective engagement as an integer element for child's intrinsic motivation [6], [7]. Existing research indicates that music cognition has a biological basis [8], which has been explained by the presence of music in all cultures, time periods and across age-groups and is supported by a growing body of research from developmental psychology [9], [10], cognitive biology [11], neuroscience [12] and music cognition [13].

While the main focus of the above-mentioned body of research is music perception, Bamberger's theory takes the perspective of child's musical development through music production. Her theory suggests that the utilization of digital technology as an additional tool for children to engage with music-making creates further opportunities for child's musical development [7]. Providing children a multi-modal context allows the discovery of new features and properties of music and scaffolds the creation of effective connections among them. This supports their process to actively construct their perceptual musical models by exhibiting long-term sustained engagement with music-making actions.

We build upon Bamberger's theory to investigate the process of music-making in the period of rapid cognitive development in early childhood. During early childhood, executive function abilities, such as memory, decision making and reasoning become gradually more mature through the action-perception interaction. In this context, we consider that this interaction is formed by processes of exploration and selection within the context of multimodal experiences in order for the individual to achieve emergent order and complexity [14], [15]. Additionally, during early years, children do not have explicit conceptual knowledge of musical elements, which allows the emergence and development of cognitive process based on novelty. A further understanding of the mechanisms of change as well as of the transition processes from simple towards more complex cognitive functions in biological systems may provide insights for the design and implementation of developmental artificial systems.

II. Objectives of the Study

The current study aims to contribute to the dialogue regarding the emergence and development of certain cognitive skills in biological systems. More specifically, it draws inspiration from recent insights into developmental approaches of human cognition from a psychological perspective to investigate the novelty-based process which scaffold humans' transition from spontaneous to deliberate actions. First, we aim to identify the emerging actions during music-making by taking a developmental perspective and looking at the changes throughout repeated sessions. Second, we examine the correlations among various emerging actions in order to reveal possible relationships among them. Third, we map the mechanisms of cognitive change over time, which allows for a dynamic approach of the conceptualization of their structure. Lastly, throughout the study, we aim to identify possible emerging patterns of the sequence of actions, which would allow us to take a developmental perspective about the cooperation of various individual actions.

III. Methodology

We adopted the methodological paradigm of microgenetic analysis of learning which has been used for the investigation of cognitive development based on behavioural observations [16] [17] [18]. This technique allows the concentration on individual participants, while the examination of any experimental manipulations and group comparisons was beyond the scope of the study. We used a multiple case studies design with repeated sessions. The micro-genetic approach is characterized by (i) observations that span a period of rapidly changing competence; (ii) the density of observation within this period is high, relative to the rate of change of the knowledge or skills of interest; and (iii) the observations of changing performance are analyzed intensively, with the goal of inferring the representations and processes that gave rise to them. A thematic content analysis was conducted of the relevant verbal and non-verbal actions according to the annotation scheme as described in section III-B.

A. Settings and Participants

The constructionist environment, as proposed by Papert, represents a compelling medium in which the child explores and learns from feedback in various forms [2], [5]. This environment allows for ownership on the process of construction and affords the learner access to concepts and strategies that confront and build on intuitive knowledge [5]. Based on these principles, we selected two interactive digital environments, without having conflict of interest, which were based on graphical representation of sound and allowed sound manipulation along with musical composition, namely the Reactable [19] and the Sibelius Groovy [20] see Fig. 1. In this way the participant children had a self-initiative role, they were free to select between the two tools and they could determine the duration of their engagement with the music-making activity. The facilitator was present in the session but had a minimum role with no instructional interventions.

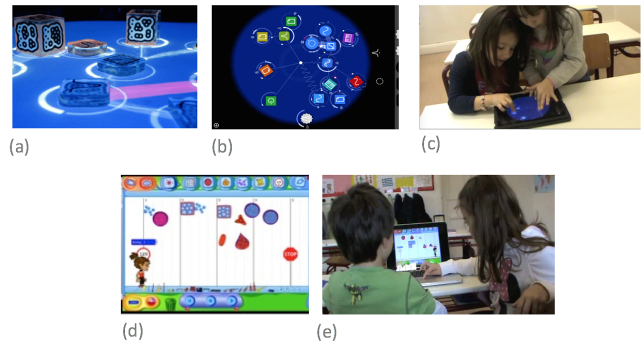

Fig. 1. Behavioural study: Settings.

Participants included 16 children (4 of them were excluded due to technical issues) resulting in $N = 12$ children (6 girls) aged 53 to 79 months ($M = 69 months, SD = 7,39$). The participant children had no previous experience of formal music education and of computer-supported music-making activities. They were asked to freely construct musical pieces in pairs in weekly sessions over a period of maximum 8 weeks.

B. Determinants and Annotation Scheme

For the development of the annotation scheme, we conducted a pilot study with 4 participants [21]. We used the Sounds of Intent framework (SoI) [22] as a starting point to develop the annotation annotation scheme of behavioural manifestions. According to the principles of the micro-genetic analysis, the focus of the annotation was put on individual's micro-behaviours. The annotation scheme was consisted of 24 verbal and non-verbal actions which fall under 5 categories. In this paper we report on the following categories: actions that indicate cognition-related behaviours (C1 to C6); actions that indicate music-induced affective engagement (E1-E5); and actions that indicated reference to the affordances of the provided digital tools - the graphical user interface (I1-I2). For a detailed description, see Table I.

C. Behavioural Analysis

In total 69 sessions were conducted, which resulted in 1795.51 minutes of video-taped data. Each pair was video-

Annotated Actions		
Code	Action	Description
C1	Spontaneous actions	Random use of sounds without any continuity
C2	Exploratory actions	Intentional attempts for investigation of a specific sonic or musical feature
C3	Assessment	Verbal characterization of the preceding musical selection
C4	Reasoning	Explanation of musical choices
C5	Deliberate actions	Explicit musical selection after repeated previous trials
C6	Planning	Communication of the subsequent musical choices
E1	Musical preference	Non-verbal expression of musical preference e.g. facial expression and vocalizations
E2	Anticipation	Verbal utterances about upcoming sonic and musical events
E3	Surprise	Verbal or non-verbal expression of surprise
E4	Motor expression	Music-induced body movement
E5	Singing	Humming or singing along with the produced music
I1	User interface interaction (1)	Verbal reference to interaction with the graphical user interface
I2	User interface interaction (2)	Non-verbal reference to the graphical user interface (e.g. pointing)

TABLE I
ACTIONS AS THEY APPEAR AT THE ANNOTATION SCHEME: C (COGNITIVE ENGAGEMENT), E (EMOTIONAL ENGAGEMENT) AND I (INTERACTION WITH THE DIGITAL ENVIRONMENT).

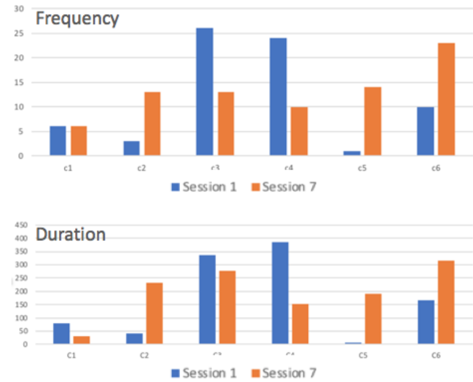

Fig. 2. Count and duration of events that indicate cognitive engagement (C1-C6) in Session 1 and Session 7 for individual child (P10).

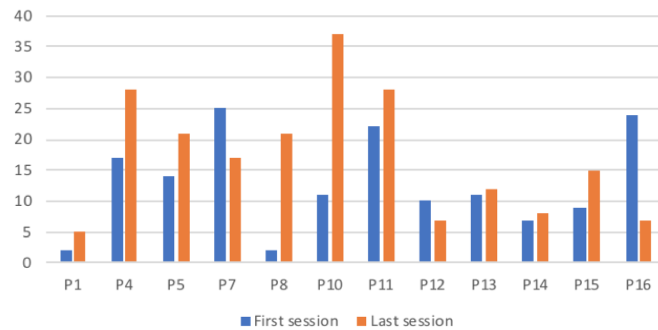

Fig. 3. Merged deliberate actions (C5) and planning (C6) per participant for the first and the last session

recorded separately at the computer lab of a public school. Participants' behaviours were transcribed individually and they were annotated off-line. The data consist of 7063 annotated actions (micro-behaviours) of 12 individuals.

1) Sum and duration of cognition-related actions: In total we annotated 3468 instances of cognitive actions throughout all sessions for all participants. The action with the highest frequency is C3 (evaluation of the musical outcome), which is followed by C4 (reasoning), C2 (exploratory actions), C6 (planning), C5 (deliberate actions) and C1 (spontaneous actions). Since these actions occurred during repeated sessions, we examine each C action in the first and the last session to observe the development. Fig.2 shows that there is an increase in the occurrence of C5 and C6 and decrease in the occurrence of C3 and C4. We consider the duration of the C actions in the first and the last session, which reveals that the duration C1 decrease in the last session while there is an increase in the duration of C5 and C6. The increase of the frequency of more complex action (C5 and C6) in the last session indicates the gradual stability of those actions over time. A closer look to the individual data, for only the merged occurrence of C5 and C6, for the first and the last session reveals that 9 out 12 children increased the execution of these complex actions in the last session (see Fig. 3).

2) Correlations: We calculate the Pearson correlations to examine the relationships among the occurrence frequency of actions. Due to the small sample, the p-values generally were relatively high; here, we only discuss correlations with $p < 0.1$. As for correlations between the C actions, the frequency of C1 (spontaneous actions) was correlated with C4 (reasoning), $r = .628, p = .029$, C2 (exploratory actions) was correlated with C3 (evaluation of the outcome) $r = .542 p = .068$ and C5 (deliberate actions) $r = .616, p = .033$, C4 (reasoning) was correlated with C6 (planning) $r = .632, p = .027$, and C5 (deliberate actions) was correlated with C6 (planning) $r = 617, p = .032$.

In addition, according to the literature, human learning is associated with the affordances of the provided tools. In the context of the current study, we were interested in the additional affordance of visual representation of the sound. We assessed the relationship between frequencies of each cognitive action (C1-C6) and the explicit references to the graphical user interface I1 (verbal utterances) and I2 (non-verbal actions). The occurrence frequency of C1 (spontaneous actions) was correlated with I2 (non-verbal behaviours) $r = .502, p = .096$, that of C2 (exploratory actions) with I2, $r = .657, p = .020$ and that of C6 (planning) with I1 (verbal utterances related to the visual representation) $r = .521, p = .082$.

Lastly, since the music-induced affective engagement has been considered as an indicator of the emergence of meaningful musical outcome, which functions as a intrinsic motivator, we assess the relationships between all C actions and all E actions. The results are summarized in Table II.

Correlations between C and E actions			
var1	var2	Pearson r	p-value
C1	E1	.528	.077
C1	E4	.733	.006
C3	E1	.503	.095
C3	E2	.581	.475
C3	E4	.754	.004
C4	E1	.813	.001
C4	E4	.789	.002
C6	E2	.753	.004
C6	E4	.777	.002
C6	E5	.517	.084

TABLE II
CALCULATION OF CORRELATIONS BETWEEN C (COGNITIVE ENGAGEMENT) AND E (EMOTIONAL ENGAGEMENT) ACTIONS.

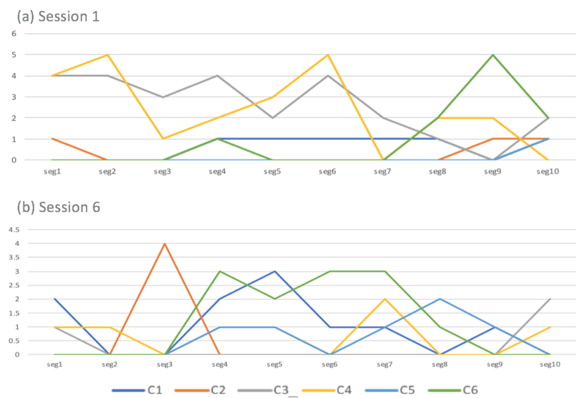

Fig. 4. Cognitive behaviours per segment for all sessions,P10

3) Development of cognitive-related actions over multiple sessions: To examine the development of the actions over multiple sessions, we normalized the duration, we segmented the sessions into 10 segments and we calculated the frequency of actions over time per participant. Fig. 4 shows an example of the development of the C actions occurrence over session 1 and session 6 of the same individual child (P10). Below, we elaborate on the development of the C actions for P10.

As shown in Fig 4, the individual processes multiple strategies (C1-C6) during music-making. In session 1 at the first segment, C1 appears together with C3 and C4. The child continued with C2, which appears from segment 4 until segment 8, while C3 and C4 diminish. Towards the end of the session, from segment 7, C2 diminishes and the individual started to exhibit C6, with a peak of occurrence of C6 in segment 9. On the contrary, in session 6, the same individual exhibits more stable C6 (planning actions). In segment 2, there is a peak of C2 which eliminates while for the rest of the session the child exhibits C1 but less frequently C3 and C4. However, the individual exhibits increased C6 starting from segment 4 until segment 9.

The above-mention description depicts the process of the use of specific strategies during the first and the last session of one child. The depiction of the actions over time provide information regarding the gradual development of the actions from spontaneous to deliberate from the first to the last session, and some structural characteristics of this development. The less complex spontaneous and exploratory actions appear through out the sessions. This means that the child is keen to explore further novel musical elements. But at the same time, the child utilizes the emerging musical elements - while verbally reflecting on them - to proceed towards more complex deliberate actions and planning. While less complex actions are initially popular and then fed away, more complex actions start become frequent before the elimination of the less complex. However, since the system provides the opportunities for further exploration on novel musical elements, the less complex exploratory actions become again apparent. The child proceeds to more complex actions of planning more frequently in the last session. While this process differs among children, the structure of the development of C actions takes always the form of overlapping waves.

4) Analyzing subsequent actions: To gain a more refined understanding of processes of change and typical action sequences, we considered transitions between subsequent behavioural actions. For this, employing a specific action vocabulary of interest (e.g. only the C actions, or all actions), we iterated over the coded session log of a participant in sequential order, encoding what action of interest in the vocabulary went before a currently observed action of interest. In other words, if all actions of interest would be encoded as a string sequence, we took all 2-grams of this sequence. Subsequently, we computed the relative frequency of each transition, obtaining empirical transition probabilities. These were visualized in matrix form to highlight the most prevalent transitions observed within a session.

In Fig. 5, we show the average transition probability matrices for the first and last session, taken over all participants, considering all actions in our behavioural corpus. As a consequence, this matrix shows what transitions are most strongly evidenced for the first vs. last session, and thus indicates common behavioural differences between first-time interaction and the final session.

In the matrix belonging to the first session, we notice high transition probability between C3-E3 and C3-C6. This means that children's evaluation of their musical outcome is highly likely to be followed by by an expression of surprise and by a deliberate action of music-making. However, for the rest it shows less stable patterns than the matrix of the last session, which is expected, as the children may more actively be exploring without clear strategies. In the matrix of the last session, more dominant dedicated transition patterns are observed. It is shown that there is high transition probability between C1-E5, C2-E4 and C3-E3. This means that the spontaneous actions of music making (C1) are highly likely to be followed by a spontaneous musical activity, in this case singing. Similarly, the exploratory actions are likely to be followed by music-induced body movements (E4), while the evaluation of the musical outcome to be followed by an expression of surprise. The matrix of the last session shows a high transition possibility to E4 and C6, which means that in the case of non-verbal reference to the graphical user interface, such as pointing (I2) is highly likely to be followed by body

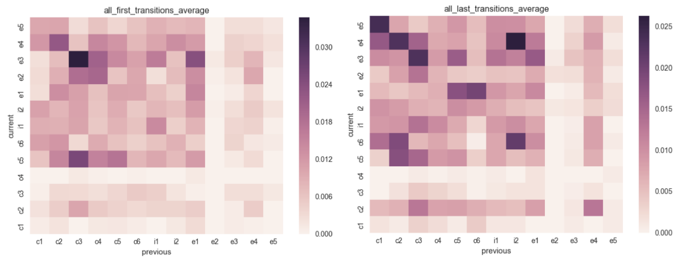

Fig. 5. Transition probability matrices for the first and the last session, averaged over all participants, considering all C, I and E categories of actions.

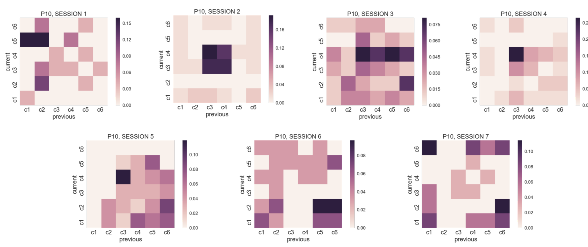

Fig. 6. Transition probability matrices for participant P10 in each session, considering the C categories only.

movement and deliberate music-making.

To illustrate how the transition matrices are examined to inspect behavioural development over time, we report an example for child P10 (Fig. 6). The matrix indicates a high transition probability between the actions C3-C4 across the 7 sessions, especially in middle sessions. In the first session, C5 can be reached, but mostly from C1/C2, and not the other way around. In later sessions, C6 clearly is more frequently reached than in previous sessions, while the child actively mixes deliberate actions and planning (C5/C6) with spontaneous and exploratory actions (C1/C2), in both directions.

IV. Summary and Discussion

In the current study, two main topics were addressed: First we identified the types of actions that emerge and develop in the case of novelty-based cognitive engagement in early childhood and their correlations. Second, we examined the developmental trajectory of the process of change via the identification of possible patterns of these actions over time. To address the first topic, we captured the occurrence of a set of actions in the context of unstructured computer-supported music-making activities over repeated sessions of maximum 8 weeks. This study was intentionally not designed to be a well-controlled experiment. Instead, our goal was to observe children's novelty-based actions in a self-initiated, naturalistic environment that allowed the unstructured emergence of task-related actions based on child's intrinsic motivation. To address the second topic, we considered the frequency of the appearance of the C actions over one session per individual and we plotted transition probabilities matrices with the actions that are reported in this paper. Below we discuss the main findings:

Gradual consistency of the occurrence of complex strategies Our results indicate that the actions of deliberate music-making and planning appear more stable in the later sessions. All the participant children were able to perform deliberate actions of music-making and verbally plan their next steps; 9 out of 12 participants exhibited an increase in the occurrence of complex actions of deliberate music making and planning in the last session. All participants exhibited the whole set of C actions including spontaneous and exploratory actions as well as deliberate music-making actions and planning, which indicates their importance in the developmental process. This research was not planned to have an experimental design; however, our findings provide initial indications about pre-schoolers' ability to engage in *deliberate compositional activity*, given the appropriate tools and the settings for execution of spontaneous and exploratory actions. These findings contribute to the current literature of music development in early childhood [23].

Developmental trajectories in the form of overlapping waves Our results indicate that in the specific context, the transition towards more complex actions is supported by a set of successive actions with overlapping phases. As children's ability increase, more mature strategies (C6) tend to dominate their strategy selection. However, spontaneous and exploratory actions are repeatedly present throughout the activity with repeated session, in the case of the individual being motivated for further discoveries of novel musical elements. In this case the emergence of a strategy starts before the complete elimination of the previous one and supports that stability of more complex actions.

Music-induced affective engagement The data revealed a strong correlation between any actions, which relate to children's music-induced affective engagement during their music-making, and actions of cognitive engagement. Given the unique domain-specific nature of music [8], we were able to observe behavioural manifestations, which imply affective and musical engagement such as body-movements, dancing and singing. Child's affective engagement with a specific task transforms the task into a fertile area for children to be sustainedly engaged [2] and to develop meaning for the musical products, which in turn function as initiators for the development of children's intrinsic motivation, as a necessity for the child to construct knowledge and master a skill.

Tension between action and symbol The visual representation enriched sound and music with an additional modality, which was utilized as a scaffold for the children to perceive and make use of various musical elements through spontaneous, exploratory and deliberate actions. The relatively high correlation among children's verbal or non-verbal explicit reference to the graphical user interface (I1,I2) with the occurrence of complex actions of deliberate music-making (C5) and planning (C6) indicates the use of the concrete visual representation of sound for music-making and the transition from concrete actions to symbolic understanding (C6). This is in line with the notion of tool in a gibsonian fashion for the development of symbolic representation and learning [24]. The tool in this case has a catalytic role for children's generation of novel strategies and for their developmental potential in the context of music-making.

V. Implications and Future Work

Deeper insight into the trajectories from spontaneous to deliberate music-making will allow for us to construct dedicated theoretic models for the emergence of increasingly complex music-making behaviour in young children. In similar fashion to the work in [25] on modeling curiosity-driven tool use, inspired by Siegler's overlapping waves theory, in future work, we also intend to computationally model and simulate novelty- and curiosity-driven discovery of increasingly complex music patterns. In our case, the achievement for the agent to focus on will be the construction of more complex creative musical artefacts. At the same time, enjoyment of the agent during this process may be more important than sophistication of the final outcome: the music-making setting is intended to create a deliberately playful experience for the child. Our current study already gives some insight into the agent's enjoyment over time, through the coded emotional responses of the children. This will need to be investigated more deeply for further modeling, and be combined with interest models in various actions and/or dedicated musical elements.

Deeper data-driven analyses may further reveal characteristics and causes of development from spontaneous action towards more complex and deliberately planned cognitive actions. As discussed before, all children did not have explicit conceptual knowledge of musical elements, so interacting with these elements could be considered as a novel activity with many creative exploration opportunities. At the same time, it will be interesting to more deeply investigate how the spontaneous discovery of novel musical elements may cause further directed exploration, and as a consequence, deliberate and planned musicking. At present, the behavioural data has only been coded in terms of actions and not in terms of musical content. However, the sessions were recorded. Therefore, for future work, we plan conducting deeper analysis of the recorded audio, in order to conduct more fine-grained music content analysis of the children's creative work in relation to their actions. This will e.g. allow for us to identify what (combination of) musical elements may most strongly have led to further investigation by the child towards deliberate music-making. It may also give insight in the extent to which children working in pairs may have creatively influenced each other.

Through such models, and taking into account the role of interface interactions in relation to musical discovery and creation, we ultimately intend to identify *how* and *when* intelligent and adaptive tools can assist and support the child in reaching more complex levels of music-making, possibly pushing the child's developmental potential [7] in non-obtrusive and playful ways. The form of the technological solution may be an application or tool, but also can be formed as a more social robotic or virtual partner.

Acknowledgment

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