A Multimodal LEGO®-Based Learning Activity Mixing Musical Notation and Computer Programming

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ABSTRACT

This paper discusses a multimodal learning activity based on LEGO® bricks where elements from the domains of music and informatics are mixed. Such an experience addresses children in preschool age and students of the primary schools in order to convey some basic aspects of computational thinking. The learning methodology is organized in two phases where construction blocks are employed as a physical tool and as a metaphor for music notation, respectively. The goal is to foster in young students abilities such as analysis and re-synthesis, problem solving, abstraction and adaptive reasoning. A web application to support this approach and to provide a prompt feedback to user action is under development, and its design principles and key characteristics will be presented.

CCS CONCEPTS

• **Social and professional topics → Informal education**; • **Applied computing → Sound and music computing**; **Education**; *Interactive learning environments*;

KEYWORDS

Music, Education, Visual Programming, Informatics education, Algomotricity

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1 MULTIMODAL LEARNING IN THE CHILD DEVELOPMENT: A SOCIO-CONSTRUCTIVIST APPROACH

Multimodal learning involves both the ability to understand through multiple sensory channels and the acquisition processes of symbolic-cultural systems in natural contexts; the proposed approaches in this work are those of semiotic perspective [13] and of ecological theory of human development [7].

In their first six years of life, children learn to use their mother tongue in familiar and social contexts, and to adopt the symbolic/cultural systems of their own community. The child development psychology defines this phase of life as the 'mastering of symbols period', which implies acquisition of syntax, semantics, and the pragmatics of specific semiotic codes in different use contexts. Together with language development, the child builds a way of thinking driven by reasoning and by more and more refined conceptual abstraction processes close to the elaboration of actual theories [10]. Moreover, with the emergence of superior psychic functions a meta-cognitive language arises, and this language can be referred to mental and emotional stats, and to all that concerns cognition and will.

About the close interdependence relationship between the development of thought and language we know that the way to construct conceptual categories in children has nothing to do with the classification grounded on necessary and sufficient definitional characteristics typical of adult logic reasoning; anyhow, the latter are organized around representative examples or prototypes, completely personal schemes which synthetically represent experienced objects and situations.

An emblematic example of this kind of learning are holophrases, single words encoding a sentence dense of pragmatics, that is linked to it use value. Moreover, the gradual and spontaneous construction of rules by induction is based on representations called *scripts* [20]. A script implies the identification and orderly placement of features associated to a recurring event. Developing a script is not a *tout court* linguistic activity: it is the re-presentation of an episode that builds mnestic traces of actions and interactions in a specific context which tend to recur and in which there are recurrences; of course, life contexts are multimodal by definition. When language consolidates, however, the script-based and the linguistic experience overlap. Scripts are needed to understand and to foresee consequences of "multilingual" situations; they serve as memory support, that is new experiences attach to them. Knowledge of scripts is manifested in the game of fiction, but also in games related to design and in a developed ability in identifying and producing completely personal codes. Treating an object or a sign as if it was another one, an action initially explorative, and then more and more intentional implies a meta-implicit representation of a knowledge interacting with imagination and with the effects of one's own intervention on the world. A second important issue is the analogy how different symbolic systems are learnt. Gardner [9] has shown that in the child development the construction of symbolic systems is not only related to specific domains, but there are periods of "transfer" between systems, especially in the case of expressive or constructive experience. Following Bruner [8], there are mainly three forms of

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representation guaranteeing a transfer: sensor-motoric representation, iconic representation, and symbolic (that is, conventional) representation. Understanding a concept by means of sensor-motoric representation means that an individual knows the world through his own actions carried out on the world and those observed; exposure to different languages and interaction with others through iconographic or conventional systems allows several access points to information and thus the formation of concepts which in school belong to specific disciplinary domains, each with its own notational system. Bruner's hypotheses have been later on developed in Gardner's multiple intelligence theory, intelligence possessed by all individuals in different forms. Such intelligences reflect the potential in solving problems by using different symbolic-cultural systems: logical-mathematical, linguistic, musical, intrapersonal, interpersonal, naturalistic, bodily-kinesthetic, existential intelligence. Multiple intelligences in child development are potential, in the sense that they exist in power, as they require specific learning environments to practice. A multimodal learning environment may be defined as a device regulated by variables external and internal to interacting individuals; the key feature is the responsiveness of the learner [19]. This means that what happens depends on actions and on the interactions among people and artifacts in use. Among the essential variables of such a learning environment, motivation and emotions play a dominant role. Particular importance is given to intrinsic motivation, that is, the condition for which an individual is brought to learn because it is repaid by the mere activity which fills curiosity and puts to the test one's own abilities. While student activation is one of the most relevant external variables in the purpose of an intense involvement, such as for instance in game situations. It is no coincidence that the fictional or constructive game are emblematic universal display of the mode of being and of thinking of children, a thought connecting the diversity of ways in which it is able to form, with its own cognitive styles and personality traits, and the different ways of communicating the cultural context in which it fits.

2 ALGOMOTRICITY

The *algomotricity* approach [5] has been recently introduced in order to propose an active teaching methodology expressly tailored in order to design learning activities focused on informatics. This approach, highly inspired by constructivism and – as such – promoting the understanding of concepts as an autonomous (though oriented by a facilitator) discovery on the part of pupils, has the aim to foster a view of informatics focused on its key activity of automatic processing of information, rather than identifying it with the use of technological devices or computer applications [6].

An algomotoric learning experience typically exploits problem-based learning and the experiential learning theory [11, 12]: participants are immediately faced to a problem and asked to investigate it, working in small groups. At first, tangible or manipulative activities are proposed, so that pupils can start to implicitly build their own mental models of the problem under study. A second round of activities, using pen and pencil or other specific tools, is devoted to an abstract reformulation phase allowing to formalize and test the models. Finally, during a computer-based activity pupils are confronted with specially conceived software which they typically get rapidly acquainted with, because the preceding phases have raised their proficiency in using these applications in order to solve specific problems.

Several workshop activities using the algomotricity approach have been proposed, embracing subjects such as computer programming [14], information representation [4], and even "advanced" topics, e.g. the use of greedy algorithms [15] or recursion [16, 17] as problem-solving strategies. Recently, this methodology has also been applied to an interdisciplinary context mixing music and informatics [3]. In particular, an activity in which the manipulative phase is based on LEGO® building bricks has been proposed for students of primary schools [2].

3 LEGO® MUSIC NOTATION

Common Western Notation (CWN) is the standard way a score is represented in our culture. In a previous work [2] we introduced *LEGO® Music Notation* (LMN) as an alternative way to represent music scores through bricks properly placed over a building baseplate.

Basic LEGO® blocks have the shape of a parallelepiped, sized $W \times H \times D$, standing for width, height, and depth respectively. In the following, we will assume that the latter parameter is not expressed, since in our proposal this dimension will not be associated to any music parameter. Taking into consideration block depth and non-squared shapes could greatly increase the number of music parameters to represent, but it would also add an amount of complexity not suitable for young learners. In addition to width and height, another key feature of construction blocks is color. The basic idea of our proposal is to dynamically map the three mentioned dimensions onto a subset of music parameters, including melody, rhythm, harmony, dynamics, note articulation, sound effects, etc., recalling the psycho arithmetic materials proposed by Montessori [18].

After establishing some commonly-accepted rules (e.g., "a 1-unit vertical slice represents the minimum duration of a note", "a yellow brick is associated to a flute sound", etc.), children can be asked to compose a melody using bricks and reflect on the final result, or conversely to start from an already-known simple tune and try to encode it using construction blocks. Please note that rules can be adapted to the learners' level, teaching situations, training goals, and they can even change during the experience.

In accordance with the algomotoric approach, these activities are carried out both during the manipulative phase and in the computer-based one, which can automatically provide a prompt feedback to user choices. The manipulative phase can follow a well-experimented scheme in which students are asked to take part in an active simulation based on a challenge: for instance, a suitably chosen jingle can be reproduced and small groups of pupils could play the role of someone having this tune in mind, yet without pen and paper at hand in order to write it down. Several LEGO® bricks are available and the challenge consists in proficiently using them in order to record the jingle. According to the subsequent activities, more or less restrictive rules might be added by the facilitator (e.g., "bricks cannot be stacked one above the other, that is they should be attached to the baseplate", or "at most four different colors can be used"). As an alternative, after a first round in which pupils are almost free, in a second one bricks have a cost and the overall budget spent by groups should be minimized. Groups are also asked to produce a written description, in the form they prefer, pending its precision in describing the jingle. Each group presents its solution to all pupils, so that the facilitator may comment about emerging similarities or peculiarities, and propose a new approach to be used henceforth. Such approach will be the one implemented in the tool described in Section 5, and the final activity will challenge pairs of pupils to reproduce tunes of increasing difficulty using that tool.

In our opinion, a first tangible result is to foster the ability of problem analysis and re-synthesis in learners, since information in one domain has to be suitably translated into a new one. Moreover, associations between block and music parameters are not predefined, rather they can be even modified in real time, and this aspect should encourage flexibility and adaptability in reasoning.

The proposed learning experience gives pupils the opportunity of experimenting within a highly interdisciplinary environment, as well as teachers either to focus their activities on different subjects or to exploit a subject in order to approach another one. More precisely, the activities intertwine the informatics and musical disciplines using the concept of *music tune* as an object which:

- can be described through suitable representations, in order to store, communicate, or play it: this leads to the realm of *information representation* or *encoding*, also suggesting that a same melody can be described through different representations, each with its own peculiarities (for instance, related to efficiency in storing/retrieving or in ease when playing it);
- can be reproduced, which usually means played, and this process is strongly related to the previous point, in that playing a melody requires the ability to retrieve a (mental or written) representation and to use it as the equivalent of a computer program to be executed in order to carry out the performance process.

Note that, as previously mentioned, the teacher can choose learning objects in either fields: for instance, students already acquainted with the execution of a musical score could be engaged in an activity aimed at introducing the foundations of programming; *vice versa*, pupils with a coding background could follow a dual activity focusing on the comprehension of musical notation. Besides, it is worth underlining that other interesting themes can be approached in this way, e.g., polyphonic scores and concurrent execution.

4 PEDAGOGICAL ASPECTS

The main research questions that emerged in the preliminary phase of this work were: 1) if, 2) how, and 3) to what extent a learning activity based on LMN could foster computational thinking aspects. In fact, such a proposal seems to be significantly different from other initiatives aiming at the same goal, but more explicitly linked to the concept of *coding* [14].

Nevertheless, some crucial points at the basis of our approach move in that direction. In order raise their value, coding activities should imply the development of logical thinking in learners. Besides, the aspects of problem solving, physical and logical manipulation, abstraction and conceptualization are typical of a design that encourages the development of computational-thinking skills. As explained in the next section, all these aspects can be adequately promoted by LEGO®-based didactic activities.

As it concerns the use of LEGO® bricks, it is worth pointing out the following considerations.

- A gamification approach fosters the engagement and motivation of students, with significant improvements in terms of attention to reference materials, participation and proactivity [1].
- At an early age, LEGO® blocks provide a more familiar and simplified language to represent music with respect to CWN, being suitable to both musically trained and untrained pupils. During an educational activity, the brick set can be increasingly extended, going from basic shapes and a limited palette of colors to non-standard pieces and a wide chromatic range. In this way, it is also possible to tune the didactic experience on the basis of students' age, music knowledge, level of attention and engagement.
- The musical meaning of brick characteristics – shape, color, position over the board, etc. – can be reconfigured, thus supporting multiple and heterogeneous encodings of a music score. This characteristic will promote conceptualization and abstraction skills.
- The LEGO®-based approach can be easily and profitably combined with *algomotricity* (see Section 2), in order to plan learning units including a manipulative phase followed by a computer-based phase.

5 WEB PROTOTYPE

The final stage of the algomotoric activity is based on the use of a computer application that recalls the aspects already explained to students and experienced during the previous steps. To this end, we are developing a web framework, whose main design principles are:

- *intuitiveness*: since the application addresses very young learners, it has to present a limited number of easy-to-understand controls, providing a clear feedback in terms of graphical and audio output;
- *flexibility*: the framework aims to foster computational thinking, so it has to support the association of different music parameters (e.g., pitch, rhythm, and ensemble) to different features of construction blocks (e.g., position, size, and color);
- *playfulness*: in order to engage young users and to maintain continuity with the manipulative stage of algomotricity, the layout should recall as far as possible the popular construction-bricks game;
- *availability*: the application should be free, highly available, compatible with most operating systems and computer architectures, easy to distribute and to update. For all these reasons, a web-based interface seemed the most natural solution.

The interface, shown in Figure 1, gives great relevance to the platform where construction blocks can be placed in order to create/recreate the score. The behavior of this area is adaptive. First, there is virtually no limit to the extensibility of the board in the two dimensions, thus allowing the encoding of very long music tunes as well as multiple parts spanning over a number of octaves. Besides,

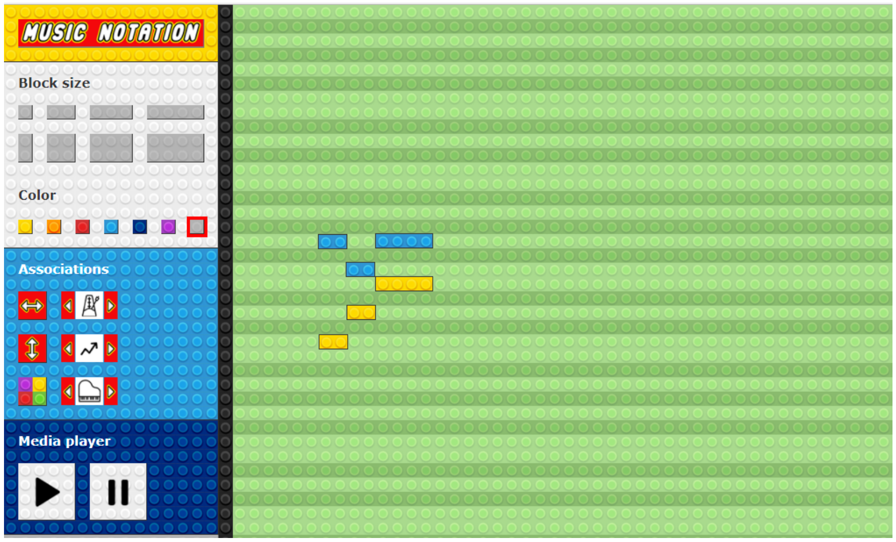

Figure 1: The interface of the web application.

even if the basic background color is green, it can be automatically modified by choosing parameter settings. For example, if the user adopts the 12-halftones scale, sets the height of halftones to 1 unit, and selects the vertical axis to represent pitches, the board presents alternate colors in order to guide user input, as shown in Figure 1.

The left panel contains a number of controls. First, it allows the choice of the size and color of the blocks to be dragged over the platform. Also after positioning, block characteristics can be edited and pieces can be removed from the board through drag-and-drop actions.

The middle part of the panel provides the user with the possibility to choose associations among block characteristics and music features. A standard preset that may recall the piano- roll view of MIDI sequencers and digital audio workstations consists in assigning the x axis to rhythm-related aspects and the y axis to pitch-related ones. Colors can be associated to dynamics or other sound effects, or they can differentiate voices as well as musical instruments.

However, the idea is to foster a flexible approach to the interpretation of the score, so students should be encouraged to adopt non-standard associations or to change their initial point of view about the encoding, i.e. to read the score in different ways. Needless to say, a change in the meaning of parameters can have a dramatic and surprising impact on the final result. For the sake of clarity, let us introduce a simple example based on a 4×2 block. In a layout where rhythm is mapped onto the horizontal dimension, pitch is mapped onto the vertical one, and each vertical slice is made of 2 units, this block represents a music note spanning over 4 time units, say a quarter note. Now let us flip the two mentioned associations and assign a 1-unit size to any pitch slice. The result is a cluster made of 4 different sounds playing for 2 time units.

Finally, the left panel contains a basic media player, fundamental to produce an audio performance of the LEGO-based score. During playback, a cursor shows the current position of the performance. Please note that in common score-following applications the cursor typically moves from left to right, whereas in this context it can move also from right to left, from bottom to top and vice versa, and even jump from a block to a non contiguous one, according to the association preset in use.

6 CONCLUSIONS

This work described an active learning activity devoted to early school stage students and focusing on a multimodal approach mixing both subjects under investigation (namely, computer programming and musical notations) as well as learning methodologies (specifically, following the algomotricity approach). The aim of this activity is that of fostering a joint exploration of computer programming concepts and of information representation within the musical domain, exploiting LEGO® bricks and specifically conceived software. As a result, the teacher/facilitator guiding the activity can choose to convey computational thinking concepts using musical notation, or to let pupils discover a simplified musical notation and its formal description.

The proposed activity, which has been motivated from a pedagogical point of view, is based on a specific software tool currently available as a mock-up, which has been also described in this paper. In the following months, such a tool will be developed especially focusing on two aspects. The first one concerns usability and the cognitive perspectives of interactions with the tool itself, having in mind how the reference users – i.e. young students – process information and perceptive stimuli. The second aspect is related to a clear and engaging game mechanics yet consistent with the algomotoric part of the learning activity, including the presence of interactive feedbacks orienting pupils when they use the tool. Meanwhile, we plan to start the organization of an experimentation phase at school and pre-school levels.

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