A Pedagogical Architecture for Designing Digital Musical Instruments

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Abstract—This article aims to present a Pedagogical Architecture (PA) for courses or workshops dedicated to the construction of digital musical instruments (DMIs) by adolescents. This architecture aims to consider the student in all her or his dimensions, not only the cognitive, but mainly the socio-affective, in order to contribute of individuals be able to act in the information society. The elements that make up this PA are organizational, content, methodological and technological. During its development, an interdisciplinary team based on principles of pedagogical robotics built a prototype of a digital musical instrument (DMI). This DMI has the purpose to serve as a model in workshops aimed at the construction of these instruments by adolescents in the educational context. The prototype of this DMI has virtual and physical interface controlled by computer. By integrating music or sounds, the construction and use of these interfaces by students is instigating and motivating learning. In addition, they foster logical reasoning, favor the creation of learning situations that involve collective problem solving, uniting theoretical knowledge and practical experimentation. The methodology adopted was a case study with 27 students from a Brazilian public school. Among the results of the Pedagogical Architecture application in this study besides knowledge related to music, programming and physics. In addition, it was realized the presence of socio-affective aspects in the students, such as motivation, socialization and their engagement during the teaching process and learning.

Index Terms—Digital Musical Instruments (DMIs), Pedagogical Architecture (PA), Socio-Affective aspects.

I. INTRODUCTION

Education is understood as a global, interdisciplinary and meaningful experience, based on a perspective that takes into consideration both the cognitive and the emotional and social dimensions of the subject. In today’s context of a society of information, characterized by the advances of the information and communications technology (ICT), one can easily see the transformations through which it goes, causing strong impacts on people’s lives, mainly on adolescents’. These impacts have influenced the way they interact, their commitment to school, their relationship with work, their emotions, their way of life, and their thoughts.

Studies [1,2] conceptualize school commitment as engagement or energy focused on a continuous action that can be observed while students interact with activities or with learning environments. This concept includes behavior, emotion and cognition. These three dimensions of engagement help understand how students act, feel and think and, consequently, how it may possibly influence their school performance.

The intensity and the quality of learning depend on motivation and engagement [1,2]. Discouraged students present low school performance, do not participate actively in class, get easily distracted, do not work enough and end up distant from the learning process. On the other hand, stimulated students can be actively engaged in their learning process by demonstrating hard-work, persistence, and enthusiasm as they carry on their tasks.

According to the Genetic Epistemology [4,5] the three dimensions - cognitive, affective and social - are built at the same time in the subject as they interact with the environment and with others and, therefore it is impossible to consider them separately.

However, the way public education is structured in Brazil does not allow, unfortunately, reaching the adolescent audience in a qualitative manner.

Indicators, such as INEP [6], evidence those facts. The percentage of students who failed attending the final years of Elementary School throughout Brazil (6th to 9th grade) is 11.1% (1,376,686 failed) and the percentage of those who dropped out is 3.2% (393,448 abandoned). Also, the age-grade gap (two or more years late) percentage is 26% [6].

Nonetheless, lack of motivation and interest is not a privilege in Brazil. Results of the Programme International Student Assessment (PISA) [7], of the Organisation for Economic Co-operation and Development (OECD), show that students’ interest and motivation when they study Sciences has decreased from elementary school to high school. The latest PISA assessment, which took place in 2015, had the participation of 70 countries, including Brazil. For this assessment, students were allowed two hours to answer questions about sciences, reading comprehension, mathematics, and collaborative problem solving. This program supports that motivation can be considered a driving force behind engagement. So, it is not enough to make sure students have the basic and necessary knowledge to get involved with complex scientific matters; they must also have the necessary interest and motivation to ‘feel like doing it’

Studies of the foundation Collaborative for Academic, Social and Emotional Learning [8], which presented results similar to the PISA ones [7], support that when the learning process covers the students’ socio-affective dimension it is easier for
them to build knowledge. Besides this, the development of social and emotional competences is verified, leading to the understanding and management of emotions. The socio-affective development also contributes to reach goals, to establish positive relationships and to make decisions.

From this reality, educational institutions must urgently interpret adolescents’ wishes and interests in order to engage them in the learning and teaching process by rearranging their linear and fragmented syllabuses, by implementing innovative pedagogical architectures (PA), aligned with current students’ profile.

Taking these reflections into account, some practices such as building up projects that include any technology developed by the students themselves are more likely to encourage and benefit not only cognition, but also socio-affective aspects, like motivation, collaboration, and engagement [9] supports that both aspects are usually observed in projects in which students themselves build tangible interfaces. An example of these interfaces is digital musical instruments (DMIs). This type of object integrates microprocessor, programming and electronics. This kind of technology instigates and motivates learning [9,10,11,12,13].

Because it includes these three elements, it is believed that these instruments are based on principles of robotics.

Based on the considerations above, this article presents a pedagogical architecture (PA) intended to designing digital musical instruments (DMIs) together with adolescents. We suggest that an educational space properly based on a PA, which takes into consideration the subject as a whole – their cognitive, social and emotional dimensions – may contribute to form individuals that are motivated, engaged and, therefore, apt to act in today’s society.

This PA was applied in a case study at a public school in Brazil. The purpose of this study is to explain the PA and its application. Thus, the article has six sections, which are: (1) introduction, (2) the concept of digital musical instruments (DMIs), (3) description of a pedagogical architecture intended to design DMIs, (4) results of the application of this PA in a case study, (5) final considerations and (6) reference.

II. DIGITAL MUSICAL INSTRUMENTS

Digital musical instruments (DMIs), for this paper, are any objects that have a digital device controlled by a computer or by any other digital supports integrated or not to electronic sensors that present virtual or physical interfaces to play sounds or music. When referring to projects and to using these instruments, [14] unlike conventional musical instruments, DMIs do not have interfaces that vibrate, but algorithms inside a computer. Besides sounds, these instruments may generate or control other types of signs, such as, for instance, mechanical vibrations, or even visual signs. These objects are part of a modern generation of electronic musical instruments, whose characteristics are to process digital signals and to have an interface that is detached from the sound source that is controlled by the computer. They are comprised of three parts: interface, signal mapping, and sound synthesis.

Artiphon1 is an example of this type of instruments. It was designed by Michael V. Butera and Jack Jenkins in 2014. The Artiphon is a device inspired by acoustic instruments. It allows the instrumentalist to play different timbres, such as the violin’s, the guitar’s, the piano’s, the percussion’s, and the contrabass’s ones. This is the reason it is also called a ‘multi-instrument’.

Guitar Hero2 and Rock Band3, both designed by the MIT Media Lab [15], are other examples of it.

In the educational context, [13] the idea of offering courses and workshops that encourage students to designing DMIs. By building this type of instrument, the authors [13] mention the successful development of competences in the areas of Sciences, Technology, Engineering, and Mathematics, known by the acronym ‘STEM’. They are designed in summer camps called MAKERS. They happen at the Institute for Creativity, Arts, and Technology (ICAT) of the University VirginiaTech in the United States of America. These courses last for 5 days and combine contents in the areas of robotics, engineering and music. MAKERS’s main goal is to boost creativity and curiosity by designing and building digital musical instruments by encompassing sensors, circuits, robotics, rapid prototyping, and software. Each summer, researchers and post-graduate students welcome about 30 Elementary and High School students [13]. This kind of course is an important aspect for the pedagogy because the students are not passive. That was inspired from the movement of making, where the people are called ‘Makers’. The Makers view products as partially complete and concern themselves to redesign products. It is not a simple acceptance what the others have given, but it means that they can create or recreating something by themselves. According to the authors, the process of making may lead Makers to a deeper understanding of personal identity. This mindset drove the first computer scientists, resulting in the current state of computing and technology [13].

Designing and building DMIs can promote engaging young people in their teaching and learning process, besides developing competences. [12,13]. This type of activity is a diversified way of working robotics [12]. The author suggests four tasks to increase students’ interest in their learning: (1) focusing on themes and not only on challenges, (2) combining art and engineering, (3) offering spaces for storytelling and (4) organizing exhibitions instead of competitions. Although most of the tools related to the design of these objects is musically limited because they were not designed for music itself, the author mentions the program Scratch4 that, in spite of not being made only for musical use, presents rich potential to designing DMIs. New approaches related to building DMIs must be tested among kids and teenagers in order to learn promising tools to develop pedagogical projects. Under this perspective, the author presents some challenges to be

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1 Available in: http://artiphon.com/
2 https://www.guitarhero.com
3 http://www.rockband4.com
4 Scratch is a software designed for ages 8 to 16 to helps them to learn programming (https://scratch.mit.edu/about).

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realized: “ [...] How should hardware toolkits be utilized in teaching DMI design? What software tools are needed? And what concepts of programming, electronics, interaction design, music and more can be taught through DMI design?” [12]. The author also questions if it is possible to create tools to designing DMIs that can be easily understood and used by students and teachers that are interested in them. These tools may thus be used to allow students to control sound through gestures in an engaging teaching and learning process, by learning content about interaction design.

In this paper, Harriman’s [12] questions are answered partially, however the main goal of this study is to investigate how the design, construction and use of DMIs can promote a learning involving the socio-affective aspects besides the cognitive ones. One way to do this is the use of pedagogical architectures for courses or workshops dedicated to building these kinds of instruments.

Therefore, the following section deals with a pedagogical architecture created specially to design and build DMIs.

III. PEDAGOGICAL ARCHITECTURE TO DESIGNING AND CONSTRUCTION OF DIGITAL MUSICAL INSTRUMENTS

In the educational context, some authors [16,17,18] have studied the pedagogical architectures (PA) for Distance Education Courses. These authors advocate that a solid foundation in one or more learning theories is important when a PA is structured [18]. A PA consists of a multidimensional structure grounded by a pedagogical model that enlightens and directs how to implement the syllabus. Accordingly, a pedagogical model is “[...] a system of theoretical premises that represents, explains and forms the way the syllabus is approached and that materializes in the pedagogical practices and in the interactions teacher-student-object of study [...]” [18]. A pedagogical architecture is structured in four aspects that relate among themselves [18]. They are: (1) Organizational, (2) Content, (3) Methodological and (4) Technological. Consequently, a PA was developed to be applied in a Music Workshop designed to build DMIs, as seen in figure 1.

![Figure 1. Pedagogical Architecture for Designing Digital Musical Instruments.](image-url)

According to figure 1, the PA is represented by four circles with arrows. Each circle refers to its four aspects. The arrows indicated that they are made in a circular shape, that is, the teacher may complement the aspects sequentially or even simultaneously and then add, modify or restructure contents, strategies, goals, technologies, and many others according to the target audience. Each of the aspects is detailed below.

A. Organizational Aspects

As the organizational aspects – presented in the yellow circle of figure 1 – were formed, the target audience (‘WHO’) for a music workshop to build DMIs was defined. The target audience was comprised of adolescent students attending the last year of Elementary School. Also, the goals of the music workshop (‘WHAT FOR’) were elucidated:

1. Offering interactions with music.
2. Inspiring students through the construction of DMIs by integrating electronics, programming and music.
3. Offering activities to construct the projects designed by the students themselves.
4. Promoting engagement in the teaching and learning process.
5. Offering interactions among students while they build DMIs and boosting team work.
6. Suggesting different gestures when they play the DMIs and thus promoting collaboration among the members of the group.

The importance of the PAs [17] are due to open spaces of interaction among the subjects through the construction and reconstruction of knowledge. The selection of communicational resources is then crucial, seen that it concerns directly the quality of the dialog. In order to do so, the construction of the structure and the organization of a teaching activity must be flexible in some aspects, such as the goals outlined, the strategies and the assessment practices applied.
An interdisciplinary team, which delivered the music workshop, was formed to make the organizational aspects. This team was comprised of the following professionals: a Music teacher, with a master’s in Education, a Mathematics and Robotics teacher, with a master’s in Physics, and a Pedagogue, with specialization in Educational Media.

B. Aspects of Content

Concerning the aspects of content, an interdisciplinary team made a prototype of a digital musical instrument called PentaTRONIX, as seen in figure 2.

![Figure 2. Digital Musical Instrument built by students](Image)

The figure 2 shows that the prototype PentaTRONIX produces sounds according to the student’s hand movements through infrared sensors and programming made in the software Scratch for Arduino (S4A). In the top part of the figure 2 we can see the students’ hand over the DMI sensor. In the bottom image, the virtual interface created by the students in the S4A is shown.

Also within the development of the aspects Of Content, a learning object (LO) was built and named ‘DMIE: Construction of Digital Musical Instruments of Education’5. The aspects of content refer to the ‘WHAT’. The purpose of the LO DMIE was to present the contents allocated in the four modules, of which the fourth is for teachers who intend to work with this kind of technology. This LO also presented problem-situations called ‘challenges’ to be solved in a collaborative way by the students [19]. The prototype DMI was used as a model to learn about electronic prototyping during the workshop. This prototype is undergoing new tests and its physical interface is being reshaped so that problems related to delay are reduced and that the possibilities to be played collectively are increased.

C. Methodological Aspects

Concerning the methodological aspects, the didactic sequence was performed according to the LO DMIE. Although it is possible to use this object in a non-linear way, the sequence of modules was followed. They are: (1) Green – Digital Musical Instruments: presents the concept and examples of (DMIs). (2) Red – Programming on Scratch and on Scratch for Arduino (S4A); (3) Orange – PentaTRONIX: offers a step-by-step guide on how to make this kind of instruments, based on a model of a DMI called PentaTRONIX. The methodological aspects refer to the ‘HOW’ and (4) Blue – Pedagogical Strategies: offers suggestions of pedagogical strategies for teachers who are interested in developing this type of technology among their students.

It’s important to highlight that the procedures of the PA plan that the construction of the DMIs should be made by groups of up to four members in order to encourage collaboration and team work.

D. Technological Aspects

Finally, for the construction of the technological aspects, the virtual learning environment (VLE) ROODA6 was used. Because the students interact inside this environment, it was possible to analyze their written records and also their productions. Besides the VLE ROODA, the physical space for the classes was equipped with a projector, a speaker, headphones, and computers to access the internet and the software Scratch and Scratch for Arduino7. Students also received a kit with a microprocessor Arduino UNO, breadboard, jumpers, resistors, infrared and Light Emitting Diode (LED) lamps.

Consequently, this PA was applied in a case study that is described in the following section.

IV. RESULTS OF THE APPLICATION OF A PEDAGOGICAL ARCHITECTURE TO DESIGNING DMIs

The pedagogical architecture presented in figure 1 was designed and applied in a case study with 27 students from a Brazilian public school, who attend the 9th year of the Elementary School. These students are between 14 and 17 years old. The case was studied in a music workshop delivered by an interdisciplinary team onsite called “Music workshop DMIE: Construction of Digital Musical Instruments for Education”. The workshop totaled 20 hours distributed into 11 classes between August and November, 2015.

For the construction of the organizational elements, an interdisciplinary team designed a prototype of a DMI to be built during the course so that electronic prototyping could be learned. In the first step, students were supposed to build a DMI prototype based on the model shown and they could choose distinctive sounds or songs as well as a distinctive virtual interface. In the second step, students had to build their own instruments that could be similar to the model presented or not.

The data collected from this case study were positive testimonials by students and teachers about the affective aspects such as motivation and engagement during the classes. Besides the testimonial’s students and teachers, videos, and another’s resources used to collect data, an online questionnaire was applied to verify the participants’ states of mind. These ones, along with emotions, feelings, interest,

5 https://lume-re-demonstracao.ufrgs.br/imde/

6 https://ead.ufrgs.br/rooda/

7 Scratch for Arduino (S4A) is a Scratch modification that allows the use of the Arduino platform (http://s4a.cat/index.html).
among others, comprise the person’s affective aspects or affection [20,21]. It is understood that these states are linked to motivation and to engagement [21]. They are also part of the emotional dimension. The questionnaire, as seen in figure 3, was responded in the last day of the workshop. The purpose of the question 5 was to collect information about the students’ states of mind during the course by asking: “How did you feel while participating in this workshop? Check the option that best represent your feeling: (1) Excited, (2) Discouraged, (3) Neutral, (4) Satisfied or (5) Unsatisfied. Then explain why you felt this way”.

![Mood states of the students](image)

Figure 3. States of mind obtained from the online questionnaire

Twenty-one students responded the questionnaire. According to figure 3, when they answered question 5, it is clear that most students, about 80.9%, declared they were excited or satisfied. Eight students mentioned they felt satisfied because they learned something new, because it was a different ‘class’ or because of the result of the work. Nine students confirmed they felt excited. They justified stating that they found it ‘cool’ or interesting because of the music or because they interacted with cables, breadboards and saw the ‘lights blinking’. One student declared he was unsatisfied claiming that there were not many choices when building the instrument. Two students were neutral. It was observed some difficulty to perform the activities among them. One student felt discouraged because he thought it was “something boring to do”. The other questions from this questionnaire were about a workshop evaluation and social connections by students.

The results of the case study show that there was predominance of the positive states of mind (satisfaction/excitement) when compared to the negative ones (dissatisfaction/discouragement or neutrality). Besides these results, teachers’ and students’ testimonials were recorded by the teachers who delivered the course. A student who had been retained several times declared he was thinking of stopping studying but, after taking part in the workshop to build the DMIs, he decided to continue his studies through an electronics course. It is also important to highlight that the school attendance in the days the project was applied increased.

Another student, whose teachers had declared she would hardly ever do the tasks or socialize with her classmates, participated in most of the activities of the group and responded the questionnaire. The connection between the social-affective and cognitive dimensions with the PA proposed is in the combination between the characteristics of the four aspects of this PA. Briefly, the arrangement of the use of music with attractive technologies such as S4A, with the LO DMIE and the use of the PentaTRONIx prototype in groups. Besides these, the challenges to solve problems, the use of virtual learning environment, the methodology used by professors.

V. FINAL CONSIDERATIONS

Considering the educational outlook in the XXI century, constituted mostly of adolescents and young people who use digital technology, teachers are frequently challenged mainly about how or what to do so that these students engage actively in their teaching-learning process. Many actions are suggested and, among them, we highlight the construction of their own projects that include several knowledge fields, such as music, robotics, mathematics, physics, sciences or engineering. It is suggested that it is possible to offer the construction of knowledge in these areas by designing and building digital musical instruments (DMIs). It is essential to develop pedagogical architectures (PAs) like the one mentioned in this study, which encompasses all the students’ dimensions – cognitive, affective and social –, in line with their profile, so that they may feel motivated and engaged in their teaching-learning process. The contribution of applying pedagogical architectures in courses, including the three aspects, happens the following way:

The cognitive aspects are related to the construction of knowledge in the areas of music, robotics, which consequently embody electronics, programming and mathematics. They build knowledge by performing activities and challenges that include logical reasoning and the ability to solve problems.

The social ones happen through activities and challenges performed in groups or pairs. When students build a DMI as a group, they must expand their skills to work collaboratively.

The affective aspects include emotional phenomena such as states of mind, motivation, engagement. In addition of the states of mind, motivation and engagement, both could realize through the frequency of the students during the classes, their active participation in the activities and the results of the questionnaires related to these aspects were evidenced.

Although the goal of this study may not be to solve educational issues such as low performance or dropout rates, it is possible to claim that students who are pleased and excited are more likely to engage actively in their teaching-learning process. Despite is not possible to dissociate emotional and social aspects from cognition, Piaget [5] concluded that these three dimensions are developed in parallel in the subject. Furthermore, the affective one has rich potential to help positively the cognition.

This pedagogical architecture was implemented with Brazilian adolescents in a public school. It is understood that this needs to be reapplied in other contexts with some modifications, in line with the goals and target audience considering that flexibility is an essential characteristic of this tool. Also, it is believed that this PA may be a model for others to be used in a diversity of situations or audiences. However, it is necessary to organize interdisciplinary teams formed by teachers both to build these elements and to deliver courses.
and workshops to the construction of DMIs. It is also suggested that meetings or gatherings should be arranged in order to prepare these professionals that may act in these courses, so that everyone involved in the project be aware of the vocabulary and content addressed in it.

Taking these considerations into account it is relevant to highlight that the most important is not the technologies used to design and build DMIs, but the combination of the four aspects of this PA. This combination with professors’ methodology helped to lead students how to design, build and use these instruments, involving socio-affective aspects such as states of mind, motivation and engagement beside cognitive ones.

The results presented here are preliminary. The next stage of the study provides for other courses and workshops, based in this PA to compare the results found here.

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