The Makey Makey Inclusive Tangible Interface and its Educational Perspectives

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Abstract. *Traditional human-computer interaction using a keyboard and mouse attached to a computer has been modified with the emergence of technologies that incorporate resources into clothing, furniture and everyday objects. These technologies open up new opportunities for designers to create innovative forms of interaction based on gestures, body movements or physical manipulation of real objects. One such innovation is the tangible interface, which allows computer users to interact with digital systems through the manipulation of physical objects. The Makey Makey interface, for example, is a printed circuit with a microcontroller that allows everyday objects to be used as computer keys. This paper presents a literature review of reported experiences with Makey Makey, the objective being to explore new educational and inclusive perspectives. For that, the main researches related to Makey Makey from 2012. The methodology used is characterized by the Goal-Question-Metric (GQM) protocol and included 14 articles in total. The results showed that the circuit can be used in several contexts, with important reports from the medical field with patients with cerebral palsy from the perspective of inclusion and motivational activities with the elderly. In addition, it was possible to verify that the contexts are varied, including entertainment, fun, games and a multitude of possibilities in the pedagogical area, especially if we consider their insertion in Early Childhood Education, integrating music and stimulating inventiveness.*

1. Introduction

Interactive multimedia technologies are increasingly present in our daily lives. Tangible interfaces allow users to interact with the computer, making it possible to manipulate the digital environment by controlling objects in the physical environment. Some of the possibilities they offer are especially promising in a learning context [Schneider et al. 2011].

First, tangible interfaces add new physical actions to the repertoire of computer-based learning activities. Qualitative results suggest that tangible environments encourage playful learning among children, people with learning difficulties and people with reduced mobility [Schneider et al. 2011]. Another important aspect is that tangible interfaces can promote and enhance social learning processes because access to a shared representation of a problem facilitates interaction and reduces cognitive load.

It was against this background that Makey Makey (MM) appeared. MM is a kit

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containing a printed circuit board with an Atmega32u4 microcontroller that acts as the interface between the board and the user by making everyday objects work like computer keys. The device implements a human interface, allowing keyboard and mouse events to be sent to a computer without installing drivers or other software. The user connects everyday objects and different materials to the board to create a tangible user interface that controls any software running on a computer" [Silver 2014].

MM thus promises to transform real-world elements into a computer keyboard or mouse button, attaching objects to the board and, in turn, sending messages from the board to the keyboard. The device is easy to use, compatible with all existing computer programs which normally support keyboard or mouse input, and does not require the user to program or even fully understand the fundamentals of electronics. Due to its simplicity, it can be used by people with no technical skills, making it possible to explore and review the resistance of everyday objects, while reusing them to do new things [Silver 2014].

This paper presents a literature review in the form of a research process that sought to identify, select, evaluate and synthesize the materials produced on this topic. The aim was to answer well-defined questions regarding the potential and application of MM in the academic context. To this end, all major studies into Makey Makey since 2012 were considered. The goals were defined by the Goal-Question-Metric (GQM) protocol, a measurement and evaluation instrument designed to provide a better understanding of processes for comparing activities.

The article is structured as follows: Section 2 presents a description of the tangible interface. Section 3 presents the methodological approach. Section 4 shows and discusses the results obtained and Section 5 looks at the pedagogical and inclusive dimensions of MM. Finally, Section 6 includes some conclusions and ideas for future work.

2. Background: The Makey Makey tangible interface

In recent years, many toolkits and tangible platforms have become accessible. They include easy-to-use programming environments, small, low-cost computers like Raspberry Pi, BBC micro:bit, 3D printers, and online communities for sharing ideas and instructions. However, while such features have made it possible for people who are not computer experts to design and development technologies, most kits still require some degree of technical knowledge and/or programming skills.

One exception to this is Makey Makey [JoyLabz, 2016], an "invention kit" intended for a wide range of users, including children, artists, educators, designers and engineers. MM has a simple yet powerful functionality: it can be used to make any physical (electrically conductive) object or living thing act as a computer key. The kit can be used with programming environments like Scratch, but also with any existing application that can be controlled with a keyboard (for example, bongo[1] and piano[2] plug-ins).

MM provides non-technical people with the opportunity to build physical interfaces without having to do any programming because the board's 'keystroke' recognition is based on resistive sensing with two wires coming out of the board: one to the user and another for the physical object that is used to detect a touch (Fig. 1). In this way, whenever a touch is registered, MM transmits a predefined keystroke to the computer. Different

[1] Bongo: https://apps.makeymakey.com/bongos/
[2] Piano: https://apps.makeymakey.com/piano/

objects can be attached to MM using the alligator clip wires included in the kit.

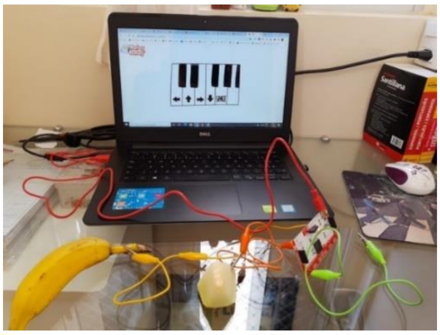

Fig. 1. A basic example of MM that can be experienced by users with their own hands. It uses electrical conductors (fruits – banana and melon) coupled to alligator clips .

Fig. 1 above illustrates one way of interacting with MM using the piano plugin. Fruits were connected to the alligator clips, the banana to the yellow clip and the melon to the orange clip. The clips were connected to the board and the board, in turn, was connected to the computer via a USB cable. The fruits thereby assumed keyboard functions and the piano keys could be activated by touching them with the hands. Other possibilities for using MM are shown in the creators' video[3].

3. Methodology

Our literature review was based on the methods described by [Kitchenham & Charters 2007], which address the steps that are needed to build a good SLR. Studies from international sources were searched for in order to identify the origins and potentialities of Makey Makey and see how the interface has been used.

3.1 Objectives

The goals of this survey were those defined in the GQM protocol [Soligen & Berghout 1999]. Table 1 shows the objectives of the literature review.

Table 1. Objective according to the GQM paradigm

Object of analysis	Scientific publications
Method	Characterization and analysis
Purpose	To determine the potentialities and applications of Makey Makey
Perspective	Creator / Researchers / Research Groups
Context	Academic

3.2 Research questions

Based on the aforementioned objectives, the following research questions were established:

1. What are the historical origins of Makey Makey, for what purpose was the technology created and how does it work?
2. What are the potentialities and scope of application of Makey Makey?
3. How has Makey Makey been used and with what target audiences?

[3] MM presentation: https://www.youtube.com/watch?v=rfQqh7iCcOU&feature=youtu.be

3.3 Search for relevant studies

The search for relevant studies was carried out in digital research databases spanning the period from 2012—the year the kit's construction was completed—to 2021. The string used in the repositories was "Makey Makey", applied to the metadata (titles, keywords, and abstracts) of articles published in three different repositories: CAPES, Scopus and Web of Science in languages English and Spanish.

3.4 Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were established in order to identify as many relevant articles as possible. The inclusion criteria used were: 1) The article was published in an international peer-reviewed journal or conference; 2) The article was published after 2012; 3) The article is written in English or Spanish; 4) The article includes reference to Makey Makey in the title or abstract.

The exclusion criteria were: 1) Repeated articles; 2) The article is not accessible through university services or memberships; 3) The article is only accessible behind a paywall; 4) Makey Makey is only mentioned as an example, but was not used in the methodology or as a resource.

After performing the searches, the titles and abstracts of the articles were verified. If an article met the inclusion criteria, the article and other information were downloaded. A total of 14 articles thus qualified for reading. Table 2 shows the results of the search for articles in the three research databases.

Table 2. Results of searches in digital repositories

Research Database:	**Number of articles found:**	**Number of articles added to the review:**
CAPES	134	8
Scopus	75	4
Web of Science	31	2
Total:	**240**	**14**

With regard to threats to validity, one potential threat was the coverage of the literature. In our case, the search string was simple, and so would not cause the omission of any articles. There may have been some studies that we did not find in our literature search, but we believed that by searching CAPES, Scopus and Web of Science, the coverage would be satisfactory. Several articles were left out, however, because they were behind a paywall. Another possible threat to validity was the filtering of the articles found in the initial search to check if the articles described a study. Articles with studies were then checked for relevance (scope), rigor, and credibility. To our knowledge, all of the rejected articles failed to meet these requirements, either because they lacked descriptions of the research context, the results, or the data analysis, because their conclusions were not based on data or because there were significant flaws in the set-up or execution of the studies.

3.5 Selected Studies

Information from the selected studies was extracted to answer the research questions in our study. This allowed us to better classify the articles and analyze their importance in different application contexts. Table 3 shows the summarized results considering the authors, the country where the research was carried out, the type of study that was carried out and the target audience (whenever this information was available).

Table 3. Selected Studies

Art.:	Authors / Year:	Country:	Object of Study:	Target:
A1	[Sansing 2012]	USA	Makey Makey Potential Assessment.	---
A2	[Lin & Chang 2014]	Taiwan	Task system to increase the level of motivation of children with cerebral palsy to perform physical activities.	Kindergarten.
A3	[Roger et al. 2014]	Canada	Case study on how retirees learn, build and play with the Makey Makey kit and what this hands-on experience suggested for them.	Adults between 60 and 80 years of age.
A4	[Silver 2014]	USA	Makey Makey Historical Analysis and Fundamentals.	---
A5	[Silver & Rosenbaum 2014]	USA	Analysis on possibilities of tangible and nature-based user interfaces.	---
A6	[Calleja et al. 2015]	Spain	Case study of the use of Makey Makey with people with cerebral palsy.	Adults between 25 and 37 years of age.
A7	[Hamidi et al. 2015]	Canada	Features of an affordable, open source communication board for users with speech or communication disorders	---
A8	[Heck 2015]	USA	Creating assistive technologies for students with special needs.	High School Students.
A9	[Lozano et al. 2016]	Colombia	Promotion of logical, problem-solving and creativity skills.	K4 – K5.
A10	[Arias et al. 2017]	Costa Rica	Literature Review of Historical Context and Applications.	---
A11	[Mäkelä & Vellonen 2018]	Finland	Case study of the use of Makey Makey in the context of special education schools.	Teachers and educational assistants between 21 and 61 years of age.
A12	[Gabriela et al. 2019]	USA	A case study exploring the types of computational thinking, creative practices, design activities, and inclusive learning opportunities offered to high school students.	High school students between 14 and 15 years of age.
A13	[Hazel et al. 2020]	Costa Rica	Case study that developed a pedagogical experience exploiting the contributions of digital technologies in the area of musical exploration.	K-12 Education teachers with more than 20 years of teaching experience.
A14	[Marín-Marín et al. 2020]	Spain	Case study that verified whether the use of MM influences different psychosocial and educational dimensions in physical education.	High School Students.

Reading the articles was of fundamental importance to be able to answer the research questions, become more familiar with the technology, its capacity and its dimensions and also to be able to estimate possible applications in the educational context.

4. Results and Discussions

Question 1: 'What are the historical origins of MM, for what purpose was the technology created and how does it work?'. In this item it was possible to identify the technology's origins. According to the creator [Silver 2014], the idea had its roots in the constructive "Camera for the Invisible" lens, a type of synesthetic lens that crossed the dividing lines between sensory modalities and made it possible to see sound as a color, feel electrical resistance as a vibration or hear temperature as a sound, the idea being to see the invisible, or what "is in front of you and you cannot perceive". The technology that preceded MM, called Drawdio Fun Pack, and MM itself were therefore tools created from a combination of experiments related to synesthetic and sensory events.

Drawdio Fun Pack was a simple device that measured electrical conductivity (the inverse of electrical resistance) between two conductive wires and emitted a high pitched sound as a result of that measurement. High conductance resulted in a high pitch, like a high soprano note, while low conductance resulted in a low tone, like a low bass note. The author further clarified that, in light of the structure underlying the Camera for the Invisible, Drawdio could be considered an input/output device, with electrical resistance acting as the input and high-pitched sound acting as the output. The difference was that there was no interchangeable input lens or output viewfinder, making it a 'simplified and less flexible camera for the invisible' [Silver 2014].

Similarly, the Drawdio Fun Pack can be understood as a timer that converts electrical resistance into audible sounds in order to get people to think of the world as if it were a musical instrument. MM is a digital computing platform, derived from the concepts of Drawdio, which uses the electrical resistance of an everyday object not to produce electrical resistance sounds but to perform computer actions. The device allows everyday objects to be connected to control software on a PC running on an operating system or on the web, just as if they were a keyboard or a mouse. It could be described as a simplified kit for turning everyday objects into touchpads [Silver & Rosenbaum 2014].

As for its purpose, MM aims to persuade people to think of the world (the conductive or insulating digital connectivity of objects) as a user interface for a modern computer [Silver 2014]. According to [Arias et al. 2017] the MM interface works as follows:

1. The device board is connected to the computer via a USB cable;
2. An electrical conductor must be connected to the board (it can be any everyday object). This conductor will be the command device: that is to say, the key or the mouse that will perform the touchpad function;
3. Alligator clips are then attached to the electrical conductor on the Makey Makey board and the user connects to the earth element.

Possible electrical conductors are very varied. They could include, for example, fruits, vegetables, tomato sauce, water and materials like pencils, graphite, paint, coins, and aluminum foil. The only requirement is that the material transmits a small amount of electrical current.

Question 2: 'What are the potentialities and scope of application of Makey Makey?'.

Regarding its scope, MM can potentially be used for activities and interactions in games, inventions and musical instruments [Silver 2014]. The creator explains that he himself realized that the usage possibilities of the basic kit were limitless and went as far as the imagination would allow. It is possible to create an interactive musical environment, "turn" people into sound machines, transform a beach ball into a gaming device and even use a glass of milk to make music. In the design phase, even the creator’s pet was involved in the experiments to check that the low voltage of the device did not pose any risk to people's or animals’ physical health.

MM also has applications in medicine, where it can be used to aid the social inclusion of people with special needs. In this regard, it has the potential to promote inclusion and prevent disabilities and limitations in activities, among other things [Arias et al. 2017]. In the teaching domain, it allows the creation of 3D circuit models that can help children map the flow of electricity and test the conductivity of materials in very specific ways [Sansing 2017]. The author also explains that in early childhood education it offers the opportunity to extend learning in content areas and to awaken children’s interest in the kind of industrial design that makes computer interfaces accessible, attractive, and effective for their users.

Question 3: 'How has Makey Makey been used and with what target audiences?'. With regard to this last research question, the results obtained show that MM can be used successfully with different target audiences, from children to the elderly, and in different contexts (educational, medical, etc.).

More specifically, in basic education MM has been used by teachers and students for school projects, with students often being actively involved in designing and building interactive settings [JoyLabz 2016]. A case study by [Lozano et al. 2016], for example, looked at activities for improving logical, problem-solving and creativity skills among fourth and fifth grade children at a rural school, with MM interactions with Scratch being used to expand teaching-learning skills. A study by [Hazel et al. 2020] described a teaching experience in the area of music education. In this case, the objective was to analyze a teaching experience comprising the design and implementation of a didactic product based on the use of MM and Scratch, relating technology with music teaching for kindergarten students. [Gabriela et al. 2019] explored the types of computational thinking, creative practices, design activities, and inclusive learning opportunities that are offered to high school students designing integrated systems using games and wearable systems that are simultaneously both physically and digitally responsive. Finally, a study by [Marín-Marín et al. 2020] verified whether the use of MM influences different psychosocial and educational dimensions in physical education.

In special education, MM has been used to design and develop solutions for students with special needs. [Hamidi et al. 2015], for example, used MM to develop a communication board for users who had speech or communication challenges, while in the [Heck 2015] project high school students used MM in a computing class to create assistive technologies for students with special needs.

In the field of medicine, [Lin and Chang 2014] implemented a system designed to motivate children with cerebral palsy to engage in physical activity. Participants in the study included children with seizures and cerebral palsy and a 3-year-old boy with moderate multiple disability, both legs weak and low vision. The objective was to find out how many times they were capable of applying physical force to touch any part of the conductive material. Another study, by [Calleja et al. 2015], looked at whether MM could be used to increase the communicative competence of two people with cerebral palsy characterized by a spastic component and severe communication problems.

With regard to older people, [Rogers et al. 2014] investigated how retirees learn, build and play, using the MM kit to see what such hands-on experience might suggest about future uses and experiences with this technology. The aim was to find out whether playing with everyday materials and electronics led to creativity and invention and, if so, in what form.

5. Pedagogical Perspectives and the Inclusive Potential of Makey Makey

The use of new teaching resources in the educational context is essential in the daily lives of basic education students [UNESCO 2015]. In this regard, playful learning stands out as a way to help motivate students, to seek, investigate, and generate new knowledge, and to work cooperatively. It also constitutes a strategy for keeping students in school not out of obligation but out of motivation. From the teaching perspective, the literature review on MM, allowed us to verify that the technology also stimulates invention, the creation of musical instruments and coding.

Music can be a fun activity. It can generate knowledge, assist in the expression of feelings and facilitate concentration, thus aiding the development of reasoning and the learning of new concepts [Hummes 2014; Guarda & García 2021]. In this regard, there are several possible uses for MM, especially in early childhood education, since its tangible interface allows children to bring their invented objects “to life”. According to [Inhelder & Piaget 2002], young children already have the capacity for symbolic representation, and can thus represent reality through mental schemes. In other words, they are already able to attribute a meaning to a decontextualized object or to new objects without the need for direct correspondence. Here, the more important things are logical thinking skills and mental operations that can aid interaction.

Moving beyond the importance of music in children's learning processes, MM has also proven to be a highly enriching technology. As pointed out in the study by [Dallazemi 2020], education—and particularly children’s education—must meet the criterion of playfulness. The author explains that working with play develops creativity and expressiveness. Teaching work in early childhood education and early grades is a task of great responsibility: it is widely recognized that it is in this initial phase is the starting point for the development of basic aspects of human growth such as interaction, speech, motor skills and coordination, sensitivity and creativity.

The author also explains that music brings with it a sense of playfulness, expressiveness, and has become an ally in the literacy process of her class. Children are eager for discoveries, for experiences, and therefore constitute an open, comprehensive source of creative exploration [Dallazemi 2020].

There remains the possibility of associating Scratch with MM. The learning application Scratch stands out for its use of design-oriented development concepts. Using this tool to program logic with blocks, a student does not need to know syntax or algorithmic structures to acquire their first experience of programming. Scratch is a graphic programming language that was invented for children to be able to create programs without needing to know coding. Instead, they program through blocks of commands that are nested together, forming a set of instructions. The purpose of Scratch is to facilitate the introduction of mathematics and computing concepts, while at the same time inducing creative thinking, systematic reasoning and collaborative work. To do this, the application allows programs to be created that control and mix images, animation, text, music and sound [Zhang & Nouri 2019].

6. Final Considerations

The objective of this study was to carry out a survey of works reporting experiences with MM in order to identify the contexts in which the technology has been used, how it has been used, and how it can potentially be used in the future. To this end, a search was conducted for articles published in the digital repositories of CAPES, Scopus and Web of Science portals.

The results of the review showed that MM has been used in a wide variety if contexts. They included major studies reporting different applications of the technology, from medical experiences with patients with cerebral palsy to the use of MM to promote inclusion and motivational activities with the elderly. Contexts were found to include entertainment, fun, games and a multitude of possibilities in the area of teaching, especially the use of MM to integrate music and stimulate inventiveness in early childhood education.

People learn more by doing, by creating. MM is therefore clearly a good bet for the future, a promising tool with which to encourage the generation of creative, expressive results by people of all ages, regardless of whether they have experience of electronics or more advanced computing. Tangible interfaces have brought about increasingly significant changes in the way people interact with computers, integrating functions into our routines ever more naturally, and facilitating more fun and playful experiences.

With regard to future work, it is our intention to develop learning activities with pre-school or early elementary school children to explore the use of MM in music education as a means of developing computational thinking skills.

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