ASTROSONIC: AN EDUCATIONAL AUDIO GAMIFICATION APPROACH

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Abstract
This paper introduces the work-in-progress AstroSonic, an educational audio-only game on the subject of Astronomy that aims to investigate the efficiency of applying game mechanics on non-speech audio content to convey non-musical, scientific curricula. First, the authors establish the theoretical framework by analyzing the positive impact of audio interaction in the context of educational and game environments, discussing the directions, in which educational audio games have been developed, and describing the ways, in which sound has been implemented for the sonification of astronomical data. Then, the first two levels of the game are presented in terms of concept, sound, and mechanics design, as well as how these reflect on the targeted curriculum by guiding players to fly their spaceship into low earth orbit and collect hazardous space debris.

Keywords: *astronomy, audio games, audio mechanics, data sonification, edutainment*

Introduction
Audio Games (AG) are electronic games that utilize mainly or exclusively sonic interaction design techniques to realize all aspects of the gameplay, including space, content, mechanics, and communication language. Thus, players need to employ their sense of hearing, in order to navigate, explore, interact, and essentially understand and perform all necessary actions towards achieving the game's goal. Due to the lack of visual stimuli AG have traditionally addressed the community of visually impaired people and thus greatly contributed to their social integration. On the other hand, they have exploited the benefits of mobile technology, and thus recently become one of the most promising genres in mobile entertainment. However, the implementation of AG for educational purposes is still an under-developed field with the majority of existing approaches focusing mainly on the subject of Music, while also relying heavily on the use of graphic representations.

AstroSonic is a research project-in-progress that aims to extend the scope of educational AG to the non-musical subject of Astronomy, and thus serve as proof of concept that AG can successfully utilize non-speech sound for the delivery of scientific curricula. In particular, an audio-only environment comprised of two levels with different AG mechanics is currently under development. In the first one, players have to guide their space rocket into Low Earth Orbit (LEO), and in the second one they have to clear up the space in their orbit from space debris. This prototype will be subsequently tested in terms of its efficiency to inform and raise awareness on the specific matters, and if the positive expectations raised by theoretical research are experimentally validated, it will be extended to deal with further astronomical aspects.

Current paper establishes the theoretical framework for the development of AstroSonic on three axes, namely the beneficial impact of interacting with sound, the directions, in which educational audio systems have already been developed, and the directions, in which sound has been so far utilized to represent scientific data. In the second part of the paper, the audio mechanics of the game's two levels are described focusing on the process, through which the targeted curriculum was embedded in the game content.

Theoretical Background

Educational Sonic Interaction Design

Since their early implementation in education, electronic games have exhibited remarkable results in supporting the learning process (Randel, et al., 1992). The latest generations of educational electronic games have evolved into systems that motivate students by giving them an active role in the centre of an interactive experience (Stapleton, 2004). Research has shown that educational electronic games promote students to accomplish their goals and abstain from prejudistic behavior (Griffiths, 2002), while enhancing their self-esteem, creativity, memory, concentration and analytical thought (Susi, Johannesson and Backlund, 2007), as well as their communication and co-operation skills (Sancho, et al., 2009).

As a sub-genre of electronic games, AG are closely connected to the aforementioned characteristics, yet this research focuses on the fundamental building block of their gameplay, which is sound itself and the facilitated modes of interaction between the user and the system through the auditory channel. This inherent feature of AG was approached from two perspectives: a) the systematic use of sound in educational interactive software to support visual information, and b) the utilization of eye-free, audio-only interaction techniques within a gaming context.

In terms of the former, many researches argue for sound's potential in helping users to develop their dexterity and master complex tools (Franinović and Serafin, 2013). Mapping the multifaceted acoustic and music phenomena to multilayered patterns of information results in the deeper understanding of targeted curricula (Bishop, Amankwatia and Cates, 2008). Sound also attracts and retains users' attention against competing stimuli (Bishop and Sonnenschein, 2012). Music interfaces in particular provide beginners with the means to become acquainted with musical concepts and elaborate on their own creative ideas without any related prerequisite (Seddon, 2007; Berndt, 2011).

In terms of the latter, the absence of visual stimuli has been found to enhance memory and concentration (Targett and Fernström, 2003). Relying solely on the perception of acoustic information clears the way for fantasy to unfold (Liljedahl and Papworth, 2008). It has also been suggested that aural stimuli can act as emotion triggers in ways possible only through the auditory channel (Parker and Heerema, 2008). Combined with sound spatialization techniques and surround sound technologies, AG gain an increased level of immersion, as players are no longer required to look at a screen, but freely explore the surrounding space instead (Röber and Masuch, 2005).

Directions in Educational AG Design

Despite this promising potential, AG have been implemented for educational purposes in a few ways, which are, in their majority, strongly dependent on graphic information, instead of exploiting the potential of audio-only mechanics. Due to the scarcity of examples, this research included not only educational AG in the strict sense of games, as systems engaging players in an artificial conflict governed by rules towards a measurable goal (Salen and Zimmerman, 2004), but also interactive systems that make use of gaming elements in the scope of delivering a specific curriculum. The following directions in the design of such systems were discerned:

- *Gamification of a music exercise*

This category includes systems that target a specific musical or acoustic property and essentially enrich a drill exercise with game elements. For example, in (Staff Wars, 2018) players control a spaceship and try to shoot down notes that are passing from the one end of a staff to the other. Pressing the key that correctly identifies each note results in a well-aimed shot. Input may also be audio itself, like in the case of the Hedgehog Game (Hämäläinen, et al., 2004), in which players sing into the microphone in order to control a hedgehog ; as long as the pitch of the melody is correct, the hedgehog stays on the right path. Games in this category are not necessarily restricted to a specific sound property, but can address a more extensive curriculum instead. In the case of (Syntorial, 2018), users are introduced to electronic synthesis by first listening to a sound, while the controls of the synthesizer are hidden, and then try to emulate that sound by manipulating the buttons and faders.

- *Gamification of a music performance*

This category refers to systems that focus mainly on music creation by providing a playful interface, through which even beginners can be introduced to musical concepts, including composition and improvisation. Such systems establish a language of communication between player and machine, not necessarily corresponding to the conventional musical language, but facilitating music interaction in the specific context of the game. An indicative example would be Xenakis' UPIC (Xenakis and Solomos, 2001), in which learners use a pen to draw shapes and listen to their audio interpretation. In that way they can apply intuitive or experienced knowledge from fields, such as geometry, design, language and mathematics, in order to play music, without being discouraged by instrumental practice. There have been quite a few such approaches, some posing musical restrictions, while others none whatsoever ; the more 'conventionally musical' control users wish to have, the further they must diverge from simply interacting with squares and bubbles in pleasant soundscapes.

The above distinction serves does not encompass all possible outcomes, which are limited only by the fantasy of the designer. An indicative hybrid approach would be Kronos (Rovithis, Mniestris and Floros, 2014), which tries to balance between the discipline of a music exercise and the freedom of music improvisation. In this project, players have to complete a series of AG, each one targeting a different skill and rewarding with a relevant module, in order to assemble their audio production instrument.

Still, in all aforementioned examples, one thing is in common: they all rely strongly on visual information for the action to take place. Thus, the third category is:

- *Audio-only educational systems*

Primarily developed towards the inclusion of visually impaired people in the learning process, such systems implement mostly text-to-speech technology, and in few cases sonification techniques including auditory icons, i.e. sounds that refer to objects or processes in a realistic way (Gaver, 1986), and earcons, i.e. sounds that refer to objects or processes in a symbolic way (Blattner, Sumikawa and Greenberg, 1989). In (Torrente, et al., 2012) the combination of these techniques is suggested for the development of point-to-click eye-free educational AG interfaces. The most commonly used one, spoken language as a medium to describe on-screen objects and processes, allows players to explore any virtual environment, and thus facilitates the extension of AG curricula to non-musical subjects, including Mathematics, Programming, Biology and Science (Balan, et al., 2014). Despite being practical though, the translation of all game elements into words restricts acoustic and musical properties, such as pitch, timbre and rhythm, from taking a central role in the game experience.

Directions in Scientific Data Sonification

The final step in establishing the theoretical framework for the design of an educational AG on the subject of Astronomy is to investigate the directions, in which sound has been used for the representation of astronomical data. Research has revealed two approaches forming an axis, whose one end hosts works of art, while the other tools for science.

The artistic approach includes works that interpret astronomical data in an arbitrary way aiming at the audience's entertainment. In essence, all music action is triggered by the behavior of the data, but without any intention of educating the listener. Any information disclosed on the process transforming the system's input into sound serves only the communication of the composer's conceptual design. A well-known example is the 1961 work of John Cage "Atlas Eclipticalis", in which the composer used a star map of Chech astronomer Antonín Becvár in a way that the position of the stars would define the notes to be played (Atlas Eclipticalis, 2018). A more recent example is "Supernova Sonata" by composer/astronomer Alex Parker, who traces supernova explosions in telescope video recordings and lets each note's intensity, pitch and timbre be defined by each explosion's distance, brightness and direction respectively (Supernova Sonata, 2018).

The scientific approach refers to systems that directly translate astronomical data to sound, in the scope of observation and analysis. Since space offers no medium for sound to travel, any wave emissions collected by the scientific instruments of spacecrafts and satellites are scaled onto the acoustic range and become audible by mapping their dynamic behavior as a function of frequency in time, allowing scientists to monitor the signals' activity through the acoustic channel and to extract useful conclusions, like for example the nature of the signal or the surroundings of the instrument that collected it. In (Spooky Space Sounds, 2018) NASA displays sounds collected from space, such as Voyager exiting the heliosphere resulting in plasma waves rising from 300Hz to 2-3kHz due to the denser gases of the interstellar medium.

Audio Mechanics Design in AstroSonic

Project's Goal and Methodology

AstroSonic is assigned to the middle part of the aforementioned axis. It does not audify astronomical data directly, but neither aims solely at players' entertainment. Its goal is to deliver information on a matter, such as the layers of Earth's atmosphere, and raise awareness on another, such as the problem of space debris, through an entertaining audio-only activity. The sonification method applied is not to remain concealed, but instead can become a tool in the hands of the teacher to explain the targeted curriculum. In terms of research, the project aims to address the following question:

- Can AG serve as efficient educational tools regarding non-musical scientific data?

The methodology followed for the design of the game is an adaptation of the one suggested by the authors in (Rovithis, et al., 2014). First, the curriculum was organised in terms of its characteristcs and sonified through parameter mapping, a technique, which maps acoustic properties to complex informational structures by seeking analogies between the two fields (Grond and Berger, 2011). Finally, the appropriate mechanics were designed to conceptually match the game's objective.

Level 1: Into Orbit

In the game's first level players have to fly their space rocket into Low Earth Orbit (LEO). To do so, they need to cross the layers of Earth's atmosphere until they reach outer space. There are 4 layers in Earth's atmosphere: Troposphere (0-12km), Stratosphere (12-50km), Mesosphere (50-80km), and Thermosphere (80-700km). Apart from their difference in size (which was quoted here on average), each one has different characteristics in terms of temperature and composition. The Troposphere is where most of the phenomena associated with day-to-day weather occur, as well as the altitude, in which most commercial jets fly. Temperature decreases with height. The Stratosphere contains the ozone layer. It is weather-free, with temperature rising with height. The Mesosphere is regarded the coldest place on Earth, with temperature decreasing with height. It is also the place, where meteors burn up. Finally, the Thermosphere is where aurora is produced. It is cloudless, contains the Ionosphere and has a temperature that increases with height.

Before applying sonification techniques to all these elements, they were categorized into continuous, including thickness and temperature, and discrete, including all other special phenomena that may occur in each layer. The former were sonified through parameter mapping on constant sounds: filtered noize, whose center frequency changes with height, was assigned to thickness and a granular texture is granulated according to temperature. The latter were realistically described through auditory icons, such as the sounds of rain and airplanes, or abstractedly represented through earcons, such as a harmonic, vibrating synth pad for the aurora.

Gameplay mechanics refer to the actions that have to be performed and repeated, in order to achieve the game's goal. One research on video games suggests that the fundamental building blocks of gameplay can be described as "Game Bricks" comprised of an action evaluated by rules and producing a result (Djaouti, et al., 2008). The design of AstroSonic was partially based on that concept, but in this case a reverse engineering process was followed. Two actions were identified as the building blocks of the game's first level: to guide (the spaceship) and to escape (Earth's atmosphere). These were then applied to the aforementioned audio content as follows: to guide was interpreted as a series of movements performed by the player with the cursor on the screen, whereas to escape was interpreted as the course from the sound of the atmosphere to the silence of space. Thus, following mechanics were designed: players must find and follow a path, through which the atmosphere's noize is high-pass filtered in an ascending way. As long as they stay on the right track, they will proceed from one layer to the other and hear the respective changes in the soundscape. The duration of each layer's path is relative to its thickness. If the frequency center of the filter is descending, it means that their spaceship is losing height and heading to the surface.

Level 2: Collecting Space Debris

In the game' second level players have to clear up their orbit from space debris. The problem of space debris (or space junk) originates mainly from artificially created objects, such as old satellites and spent rocket stages, that are now defunct. Their disintegration, erosion, and collisions has resulted in a cloud of fragments around Earth that can be very dangerous for space stations, operative satellites and, in the future, spacecrafts that pass through. All space debris were assigned to oscillating sound events, whose timbre and pitch depend on the objects' type and size, whereas distance and trajectory are signified through intensity and spatialization respectively.

The building blocks of the game's second level are to collect (the debris) and to avoid (collisions). To collect was interpreted as grabing something that lies in front, whereas to avoid was interpreted as doing it within the given frame of time. Thus, following mechanics were designed: players are constantly on a collision course with various objects coming from many directions and need to move accordingly to bring those objects to the center of the stereo field, when they are near enough to be collected.

Conclusion

It has been theoretically proven that AG can be designed as valid tools for education due not only to their inherited properties from educational video games, but also to their inherent feature of relying on sound to establish modes of interaction between the player and the system. Nevertheless, the development of educational AG focuses mostly on music exercises, with the additional help of graphic information, whereas audio-only approaches are scarce and addressed to the visually impaired community.

The educational AG AstroSonic was presented as the authors' suggestion for investigating the efficiency of audio-only game environments to deliver a non-musical curriculum through interaction with non-speech audio content. The game's development is currently in progress ; this paper described the concept, sound, and mechanics design of the first two levels, in which players fly their spaceship into Low Earth Orbit to collect space debris. Future testing sessions to evaluate whether this thesis will find empirical support are of highest priority.

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