Using the Axoloti Embedded Sound Processing Platform to Foster Experimentation and Creativity

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ABSTRACT
This short paper describes how the Axoloti platform is well suited to teach a beginners' course about new elecro-acoustic musical instruments and how it fits the needs of artists who want to work with an embedded sound processing platform and get creative at the crossroads of acoustics and electronics. After presenting the criteria used to choose a platform for the course titled "Creating New Musical Instruments" given at the University of Iowa in the Fall of 2017, we explain why we chose the Axoloti board and development environment.

Author Keywords
Axoloti, music education, electro-acoustic instruments, physical computing, open-source.

CCS Concepts
• **Applied computing → Sound and music computing** • Applied computing → Performing arts • Computer systems organization → Embedded hardware

1. INTRODUCTION
The creation of new musical instruments lies at the crossroads of arts, science, and engineering. In this interdisciplinary field, different specialties connect in a creative way; involved areas include human-computer interaction, improvisation, and interpretation. Given the long and fruitful history of creations resulting from the collision and mutual enrichment of art, science and technology, it is essential that young artists and engineers be engaged in the tradition of art-science works.
With this in mind, we created a course open to upper-level undergraduate and graduate students with majors in Music, Computer Science, and Engineering. The students who actually took the class were undergraduate and graduate students, with majors in Music Performance (trumpet, clarinet), Music Education, Music Composition (graduate students), and Computer Science.
We show in this article how Axoloti is well suited to foster creativity and experimentation.

2. A PLATFORM FOR A NEW MUSICAL INSTRUMENTS COURSE
2.1 A Course Focusing on Applied Creativity
In this course, we wanted to allow a diverse body of students – no previous experience was required in programming, electronics, or music – to develop creative projects in the limited time offered by a one-semester course. To reach this objective, we included a blend of acoustics and electronics at many levels, from the syllabus to the content of each class meeting to the design of the projects which would support the learning process.

2.1.1 Syllabus Excerpts
In this excerpt of the syllabus, we see that the objectives of the course touch multiple disciplines:

"*Upon completion of this course, you will be able to produce and read sound spectrums, find the natural resonances of an object such as a metal plate, and use this knowledge to drive the vibration of the object with a transducer, program an embedded Digital Signal Processing board [… and] collaborate efficiently between artists and scientists in order to develop art-science projects.*"
The list of assigned and suggested readings corroborates this approach mixing acoustic exploration, discovery of basic electronics, and development of programming skills. For instance, the article about David Tudor's *Rainforest* [1] as well as chapters from Collins's *Handmade Electronic Music* [2] and Nelson's *Junkyard Jam Band* [3] encourage the students to experiment with acoustic and electronics – specifically piezoelectric sensors and transducers – and shed light on the history of musical works linked to such experimentation. Chapters of Heller's *Why You Hear What You Hear* [4] introduce Fourier's theorem, spectrums, and resonance in an experimental way. Articles from the *NIME Reader* ([5], [6]) typically invite the students to reflect on the interconnections between several fields including music composition, performance, user experience design, and computer programming.

2.1.2 Project-Based Learning
In order to leverage the students' creativity in the learning process, the semester was organized around three projects. All projects had to involve both an acoustic and an electronic component.
The semester started with **Metallic Resonances**, where the class built a cymbals/metals-based vibrating installation as a group. This provided a support to study topics such as the Fourier theorem, spectrum analysis, resonance, and the use of piezoelectric sensors and transducers.
Next, each student designed and built a **Synth-in-a-Bottle**, i.e. a synthesizer or noise-maker in a bottle or glass jar. This enabled the further study of acoustic resonance and feedback loops, in addition to the development of DSP programming skills.
Finally, each student made a proposal for a **Personal Project**, including both a personal electro-acoustic instrument, and a corresponding piece/composition/performance practice. All projects were performed during public events at the end of the semester.

2.2 Criteria for a Choice of Platform
With this goal of creativity, we chose early on that the live electronics would be realized on an embedded platform: we wanted the projects to be conceived as self-contained instruments. We made this choice with the intent that students focus on "building an electro-acoustic instrument" more than on "programming a piece of software in a computer." Another goal was to address Cook's first principle for designing computer music controllers in [5]: "*Programmability is a curse*": we wanted the students to build an instrument with a limited set of playing modes, not a general purpose programmable instrument.
Given the objectives of the course, we considered the following criteria to choose a platform; they are close to the ones presented by Schmeder & Freed when they were designing an architecture for rapid design of musical instruments: affordability, process simplification, conceptual abstraction, scalability, signal quality for musical gestures [7].

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- Affordability: given our diverse population of students, this was an essential criterion. This included the possibility to develop for the platform from a Mac or a PC.
- Process Simplification: a programming environment designed to help users with no coding experience would be preferred, as well as a hardware environment optimized for direct musical interaction, for instance including audio input and output jacks.
- Conceptual Abstraction: the ability to re-use one's own code and to use code shared by others in a modular way was of critical importance to enable for fast development and test musical ideas.
- General-Purpose Input/Output (GPIO) port to support the addition of sensors and actuators; for this course, we needed support for digital inputs, analog inputs, and digital outputs.
- MIDI Compatibility: we wanted at minima MIDI input support, preferably with support for both Class Compliant USB-MIDI controllers and traditional input/output DIN MIDI connections.
- Signal Quality for Musical Purposes: we were looking for a system with at least a stereo input and output with a minimum sampling rate of 44.1 kHz, and with a General-Purpose Input/Output port with a sampling rate fitting most musical gesture needs.
- Durability: this point was not of prime importance to teach a one semester course, but thinking about the artistic potential, we were interested in building instruments and performances that someone could preserve as digital art, as described by Bressan [8].

2.3 Axoloti, a Fitting Platform

After consideration of these criteria, we retained the Axoloti Core (hardware board) and Patcher (software development) as main tool for the course. This platform has already been used successfully in creative music and research contexts [9]. Other platforms were considered: Hoxton OWL [10] and Mod Duo [11] lacked the GPIO ports necessary for easy addition of physical controls; the Teensy board was used successfully for an instrument-building course [12] but it was not readily usable (lack of jacks); the Bela platform [13] satisfies most of our requirements, though at a slightly higher cost.
We show here how our constraints were satisfied:

- Affordability: the Axoloti Core board is the most affordable board we found, fitting our requirements. Axoloti Patcher is a cross-platform development environment.
- Process Simplification: the board includes stereo audio input and output. The Patcher provides a graphical programming interface.
- Conceptual Abstraction: code includes abstraction possibilities, and is easily shared. The development cycle takes very little time.
- GPIO port: Axoloti Core includes 20 GPIO with digital input/output capabilities, and a maximum of 15 analog inputs.
- MIDI Compatibility: Axoloti offers support for Class Compliant USB-MIDI controllers and input/output DIN MIDI connections.
- Signal Quality for Musical Purposes: the converters work at 48 kHz/ 24 bits. The DSP is processed over 32 bits. Vector size is fixed at 16 samples, which results in a latency small enough for our musical goals. GPIO values are sampled at the sufficient rate of 3 kHz.
- Durability: Axoloti hardware and software are open-source, which helps with the potential durability.

Additional features include the fact that the audio inputs can accept a wide range of signal levels, for instance from piezo microphones, or line-level synthesizers – nominal input gain may be adjusted by -12 or +35 dB through software flags.
Moreover, when using sensors and low-power GPIO outputs, the board can be powered by USB.

2.4 Limitations

During this one-semester instrument creation course, we did not reach technical limitations preventing any artistic realization.
Some students – especially those with no previous programming experience – had difficulties navigating the documentation available on the Axoloti community web site. The instructor designed dozens of focused tutorial patches for the students to learn the basics of the platform.
Some particularities of the platform would take more than one semester – or a different kind of syllabus – to master, especially the use of fixed-point arithmetic. An advanced algorithm such as a reverse delay with transposition was given as a module to re-use – the scope of the course did not allow for detailed explanations of the code.

3. CONCLUSION

In this article, we showed how the Axoloti platform was well suited to teach a course focusing on the creation of new electro-acoustic musical instruments. The students developed creative projects such as an upcycled guitar pick-up, a MIDI-controlled looper, a creative delay guitar pedal; the scope of this paper does not allow for their presentation. The flexibility of the Axoloti platform empowered students to create in a limited time a great diversity of projects bridging music, science, and technology.

4. ACKNOWLEDGMENTS

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