Strictly Coding: Connecting Mathematics and Music through Digital Making

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Abstract

Live coding is a growing international phenomenon that brings together 21st century skill development through digital making, a mode of digital creativity that applies coding in the real-time of a musical performance. Live coding introduces the exciting notion of 'liveness' with composition and improvisation happening in the immediacy of performance. Coding exists as a much higher sonic abstraction than that of standard Western music notation; it affords the performer the ability to compose in the immediate or real time of improvised performance, thus merging improvisation, composition, algorithmic thinking and performance creativities through the use of new digital making tools.

Introduction

Live coding is an interdisciplinary practice and Sonic Pi is a software tool that connects mathematics and music through the real life experience of musical problem posing and solving, embodying mathematical concepts, developing of algorithms, structures and notions of variables. Children enjoy the personal and social aspects of digital making and learning live coding, along with the domain content of music and mathematically relevant problem posing questions and developing high-level of reasoning (such as 'what-if' choices and inductive reasoning through to deductive logic) which also foster flexible thinking and multiple opportunities for risk-taking.

The Raspberry Pi charitable foundation delivers low cost computing technology to a large audience of over 1 million young people and creative enthusiasts with the aim of creating the Digital Makers of tomorrow. Sonic Pi is a relatively new open-source software tool and platform for the Raspberry Pi computer, designed to enable school children to learn programming by creating music (see: http://sonic-pi.net/). In this paper we share insights from a recent research project, which develops new practices to enable, empower, inform and inspire students to engage in opportunities to create digital music, learn coding, and develop new mathematical and computational skills.

The Sonic Pi project responds to technology disruption and subcultural music practices (e.g., breakbeat and dubstep) by involving musicians as educators and computer scientists as musicians to enable young people to engage creatively with a digital instrument that is accessible and can be used to provide new forms of performance. This provides interdisciplinary ways of working and STEAM connected activities that open up new educational and business models and modalities for creating new digital creativities. The content matter provides the opportunity to teach students how to ask questions, pose problems, and seek answers in the moment of a live real-time musical performance as well as shape an ever increasing digital world.

The Sonic Pi project addresses ways in which schools can be innovative spaces for nurturing new collaborative learning digital communities through digital making. In addition, connecting music education with STEM subjects, in particular with mathematics, could also assist in the acceptance and nurturing of such new practices. In terms of connecting research and practices in the field of music education, within the STEAM framework, our paper gives illustrations of: the pedagogies and creativities developed as a result of this kind of work; and the creative ways in which coding and digital making can promote cultural, scientific and artistic exchange, and be a catalyst for change.

Learning about the Nature of Live Coding Performance in Music and Maths

Live coding music performance is a growing international phenomenon. Live coding can be viewed as a way in which computer programming is used to communicate the musical intentions of the live coder to the computer, which then produces sound as output though implementing various algorithms. Programming and mathematical skills are embodied in the code, design, abstraction and implementation. Mostly this happens in the mind of the live coder.

Like jazz, live coding can fuse the practices and creativities of performance, improvisation and (pre-)compositional elements learned from students' preceding music, coding and mathematical training. It can be enacted in the immediate moment (constituting the 'liveness') in which the creator codes or uses the syntax of a particular programming language or a translated mathematical algorithm, which may or may not be adapted by the performer. The coding style may have an important role in inspiring certain musical and creative behaviors, communications and interactions employed in live coding performance as a musical and creative practice, but how is the processes of learning to code music defined and located? How do we evaluate the exciting notion of 'liveness'? What are the outcomes for learning that can and should be assessed in music, programming and mathematics education settings?

Live coded performances of music can range from a curated piece to engaging and motivating an audience to dance (such as at a nightclub or on a beach) or to both solo and ensemble live coding shared by jazz and electronic and laptop musicians in diverse performance spaces, with the projection of code onto a screen being an important and significant feature of both the performer's programming and non-programming actions.

The coding activity may display curatorial skills, such as in the creation of a new piece from existing recordings, an arrangement of an old piece, or a newly improvised piece performed at a concert. Because, in many cases, most of the musical events of a performance takes place in a here-and-now context, each is a distinctive form in which individuals come together in order to explore a new angle on live improvised musics [1]. This raises questions as to whether a particular real time performance brings with it a set of ascribed values, or whether the creativity involved is a peculiar quality of the act or is something along a continuum involving a risk-laden to risk-free act of real time programming. Live coding introduces the driving force of change in activity as the notion of 'liveness' with composition and improvisation happening in the immediacy of performing and experimenting simultaneously. It is, however, important that students needs to be well prepared and practiced to be able to code and implement algorithms in such an intense performance settings.

Creating music through programming and understanding the output of the "musical instrument" Sonic Pi students need to build complex knowledge of how algorithms are built, be able to deal with variables and functions, and must be familiar with complex mathematical and programming syntaxes. While improvisation is imminent in such an environment, developing successful compositions requires students to have a strong foundation and understanding of the concepts listed above. The preparation for live coding and working in the Sonic Pi environment enabled our team to not only engage students in basic development of music composition, but also to develop understanding of a variety of mathematical concepts through a musical journey. While coding and composing, students often didn't even realize that they were learning mathematics and computational thinking in our environment.

This raises the potential for claiming coding and syntax errors as: (a) a source of creativity; (b) a temporary obstacle to which the audience may be privy; or (c) an act of strategic improvisation [1] for a discussion of errors / mistakes as interesting 'collisions'). However, the very complex features and the unclear nature of what live coding performance is and the complexities and diversity of what constitutes aesthetic evaluation of live coding actions [2], what learners make of, and how they become engaged in, learning to code [3, 4], and how audiences appreciate and evaluate live coding, whether in informal contexts (e.g., at home) or in formal, institutionalized contexts (e.g., at school) place new demands on music and mathematics educators and music and mathematics education.

Sonic Pi Project Findings

The Sonic Pi Project was carried out in two schools in the Cambridge area and a Summer School was organized in the Cambridge Junction music theatre with final live performances of participants. Throughout the project researchers collected data from three different questionnaires from participants as well as interviews and observations were carried out. One questionnaire was sent to participants of the Sonic Pi course, one to the Summer School students and one to project members to evaluate the courses and the project. The questionnaires were completed electronically, transformed into datasheets and analyzed with SPSS software. In the upcoming section we will outline the characteristics of participants and highlight interesting findings from the collected data.

Characteristics of the Sonic Pi Course Participants: We sent out the first course questionnaire to both students and teachers together. Out of the 50 responders there were 6 teachers and 44 students. Here we will highlight results from the student data, but further details can be found in the project report [5].

There were almost equal number of female (52%) and male (48%) students among the participants. Their ages were mostly 13 (57%) and 14 (36%) years, but there were three younger students in the group. Two schools participated in the project Coleridge, which was a higher performing town school, while Freeman, a nearby village school with more diverse background of student than Coleridge. There were slightly more participants from Coleridge school (26, 59%) than from Freeman (18, 41%). Only 5 students (11%) owned a Raspberry Pi, which necessitated the more detailed instructions for the device.

In the later part of the questionnaire, participants were asked to rate statements about music and computers to rate it on a 4-point Likert scale from Strongly Disagree to Strongly Agree.

Statement	**Mean**	**SD**
6a Music is an important part of my life	2.82	0.843
6b I enjoy composing my own music	2.48	0.792
6c I use computers to compose my own music	1.98	0.731
6d I consider myself to be a musician	2.07	0.936

Concerning the statements above, most students agreed that music was important part of their lives (6a) and enjoy composing music 6b. However, most students did not consider themselves as musicians (6d) and had little experience composing music on computers (6c). It is also interesting to observe that the highest standard deviation (.936) close to 1 is 6d suggesting that there is a sizable disagreement among students if they consider themselves as musicians, which was an interesting finding to be discussed later.

Similarly we asked participants to rate skill-related statements in a 4-point Likert scale from Not Important to Very Important.

Question	Mean	SD
7a The development of your musical skills	2.55	0.848
7b The development of computing skills	2.59	0.787
7c The development of programming skills	2.43	0.789
7d The development of creative activity	3.05	0.785

For these statements most students responded favorably that they considered music and computing are important skills. However, creativity was the most highly rated item (7d) suggesting that doing music and computing are creative activities and they were supported throughout the course.

Highlights of School Differences: We choose schools with different characteristics and wanted to see if there are differences in the perceptions of the different cohorts in the study (due to the limitation of the paper, we can not include all tables and charts, but full findings are outlined in the Sonic Pi Project report [5]). We found only three considerable standard deviation differences in statements 6b, 6c and 6d. Students in Coleridge considered enjoying music, using computers for composing, and being a musician a bit higher compared to their peers in Freeman. An explanation to this issue could be that Freeman was a more mixed economy group and had less backing from their parents. Based on the background data it was clear that Coleridge students received more formal training at home (19%) than students in Freeman (11%) and owned more Raspberry Pis at home (15% vs. 6%). We further examined this issue and from the summer school data we found that school and parents' support was a significant factor if students consider themselves as programmers and musicians.

Summer School participants received the same questionnaire, but their characteristics were considerably different than those in the school experiment. 60 students participated in the Summer School and out of the 19 responses we received only three female returns. This was a reasonable reflection of participant distribution. The summer school was more male dominated, because computer science and mathematics is considered to be a male subject and there are only two female live coders in the country. This is why it would be important to prepare a female oriented computing and mathematics environment to encourage more girls to engage with these subjects. The summer school had a different distribution of participants with formal training than the Sonic Pi course, 68% of participants had formal training compared to the 50.5% in the course. It was due to the fact that the summer school was voluntary and students wanted to make music and it offered an open environment for such aims.

The comparison of the course and the Summer School highlighted the importance of background of participants and gender related issues. It was clear that in a more relaxed environment offered by the summer school participants were more flexible to challenge their boundaries and allowed making mistakes to learn from. It became also apparent that students eager to engage in team activities and support each other to learn music, computing and mathematics. It became clear that computing and mathematics were considered as a 'boy' subject, but girls were highly engaged with the projects and became confident and even earned boys' attention and respect from their performances. In both environments the pleasure of being participated in a creative cross-discipline activity considerably contributed to students confidence in learning music, computing and understanding mathematics. The project also supported students' creativity and highlighted the need for their development in computing, musical and mathematical skills.

Theories and Models of Learning in STEAM Education

Any theory of learning must answer the questions: (1) How is learning defined and located? (2) What is learned? (3) How does learning occur and what are the key actions or processes of learning? (4) How do we know learning has occurred? So, for STEAM education, in the context of live coding learning pathways, we need to ask how does live coding offer an expansion of strategies to connect music and mathematics in a trans-disciplinary, integrative and holistic approach? Through our approach students are engaged in musical composition and performance, but the project team often indirectly or directly guided students through deep mathematical and programming contexts. In this way, we were able to connect a variety of disciplines seamlessly into students' knowledge, often in a way that students did not even realize that they learned such trans-disciplinary concepts. With a high level of interest from young people in Digital Making, the creative approach to mathematical and computational thinking helped students' inbuilt need to make their mark in an increasingly digital world using new digital tools.

Most formal learning in music and mathematics education is seen as a process of engaging in the style characteristics of presentational performances and canonic classical repertoires acquired as a code of knowledge, alongside competence on a musical instrument; this stems from academic 'acquisition' models of learning. More informal participatory competence models may involve mastering levels in musicianship and mathematics by developing one's identity in relation to the community.

Coding music performance in real-time exists as a much higher sonic abstraction than that of standard Western music notation; it affords the performer the ability to compose in the immediate moment or real time of improvised performance, thus merging improvisation, composition and performance creativities. This creates an urgent need and challenge to design new learning models (and learning spaces) for schools and informal educational contexts, and to better understand and remove the barriers for both teachers and students. It also signals the need for a new model of learning, which emphasizes collaboration and collaborative enquiry orchestrated by and between educators, researchers (from education, music, mathematics and computer science) and program designers. This presentation offers insights on how we can work hand-in-hand with young people, to navigate and create digital environments which celebrate new learning pathways and which utilize creatively a hybrid age of digital making practices.

In conclusion, the value and outcome of learning live coding practices, therefore, are as follows:

1. Young people find innovative ways to learn live coding as a creative practice that entails jamming and hanging out writing and editing computer code together as a way of integrating performing, improvising and composing through live coding music performance; there is immense potential for live coding to enhance the development of creative music making and live performance capacities in formal schooling and for digital music making to act as a catalyst for educational change as well as a new way to engage students in STEAM subjects.

2. New learning pathways are co-created by students as they engage in on-the-fly algorithmic composition through the combined practice of: (a) computer coding and mathematical algorithms (from simple to complex); (b) digital making (motivation, ownership and sharing); (c) music composition (generation of ideas, inventiveness and development); and (d) execution during performance (and its 'liveness'), whereupon risk taking becomes a source of learning.

3. Collaborative team teaching involves mutuality, reciprocity and scaffolding which are also qualities of effective partnerships working in communities of interdisciplinary experts. While there is a tendency among some music educators to rashly dismiss the legitimacy and

effectiveness of musical practices with which they are unfamiliar educators in contemporary music classrooms need to encourage students to embrace risk taking, and access new digital tools as a source of learning. Collaborations between experts, scientists, mathematicians, artists, makers, learners and between individual learners and fellow learners can enable development of creative and live coding performance pedagogies.

4. Industry-related real-world creativities which are driving creative cultures and discourses today transit better in the digital learning and training of young people in cross-aged groups with teacher teams who navigate and engage with minimal structure and maximal autonomy, jamming and learning by doing and talking. Itinerant teachers need not be isolated, working in silos, but should rather be people who take on extra responsibility beyond traditional roles as instrumental teacher employees – roles that are redefined by the diverse ways they are charged with, and expected to work across, multiple projects, new learning pathways and new performance practices.

What all of this means is that possibilities for pedagogic innovation emerge through live coding music performance. Innovative engagement with digital music making and creative pedagogies in school classrooms ignite new learning pathways and enable us to even further tighten the transdisciplinarity of STEAM subjects.

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