Designing a Game for Learning Math by Composing: a Finnish Primary School Case

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***Abstract*—Music is filled with mathematical relations. When creating music, the composer must keep in mind the rhythm, the notes, and how well they ring with each other. Our aim was to design an application that teaches these relationships and allows users to compose their own songs using numbers. Our work follows the design science research method, and we have co-designed the application together with elementary school students and teachers in Finland. This paper demonstrates the design process and provides an analysis on our design based on data collected from the participants in two separate sessions.**

***Keywords*-education; mathematics; music; design science.**

I. Introduction

The Programme for International Student Assessment (PISA) is a test that measures students' performance in reading, mathematics and science. According to the PISA report in 2016 [1], the results of mathematics performance in Finland were among the highest in 2003 and 2006, but they have decreased since. This trend, and the challenges in math education in general, could be mitigated by the use of games, as they have shown to possess a potential for learning math [2], [3]. Moreover, the combination of music and math can facilitate learning of the latter [4], [5], [6].

The 2014 revisions of Finnish curricula emphasizes the use of tablet PCs, increases hours for learning music and art, and enables teachers to combine subjects [7]. Accordingly, we propose a novel game concept, Harmony Hippo, which enables children to learn mathematics whilst composing music. Unlike most previous educational games that combine mathematics with music, our game was developed together with elementary school children using the design science methodology [8], [9]. In this paper, we focus on describing the game concept through its design process.

II. Background

In Finland, teachers widely use textbooks and teachers guides when planning on how they teach [10]. It is a customary habit for the teachers, to first give the same instructions to the entire class, and then give all the children the same exercises to solve [11]. Hemmi et al. showed that since teachers follow the guides strictly, they have only a little room to improvise their teaching based on childrens ideas [12]. This can be thought as a missed opportunity in teaching. An and Tillman argue that a school curriculum should have enough flexibility to facilitate what students learn through different approaches [5].

The Finnish national curricula from 2014 (a) enables teachers to combine subjects for making learning more effective. For example, if the topic is food, students can find information in history and geography classes. Moreover, the curricula (b) increase hours for music, thus giving a broad opportunity to apply other subjects, like math, to music classes. Furthermore, (c) the curricula recognize games and other virtual environments as valid learning environments. This way students can be involved in the development and selection of their own learning environments [7].

This study is focused on combining math education with music. There are many studies to find connections and learning effectiveness between those two. An and Tilman identified music composing as a popular way of teaching math [5]. An and Capraro found that teaching mathematics integrated with music has the benefits of improving students' attitudes and their achievement toward math [4]. Hall describes nine experiments in which pupils use audio processing software to discover important principles of acoustics and apply basic mathematics to explain them [6]. Hence, composing music has potential to benefit mathematics learning.

Another aspect of this study is using games in math class. Well-designed video games play a major role in mathematics [2], and learning math with games may increase students' learning and motivation [3]. Finally, Devlin proposes that educational math games should link to music, thinking of the game as an instrument to "play" mathematics [13].

III. Research Design

We followed the 3-cycle iterative approach of the design science methodology to create our application [8]: a design environment, design science research, and knowledge base. We engaged in an iterative design process, where in each cycle we co-design and test the application in a real learning environment. We then used the test results and our knowledge base to improve the application. We also drew knowledge from the 6-step design science methodology proposed by Peffers et al.: "problem identification and motivation, definition of the objectives for a solution, design and development, demonstration, evaluation and communication" [9].

Design science requires a design environment to test the application and collect feedback from a target group. We

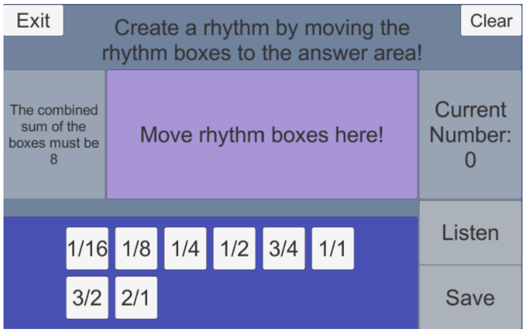

Figure 1: Rhythm composing in version 0.1

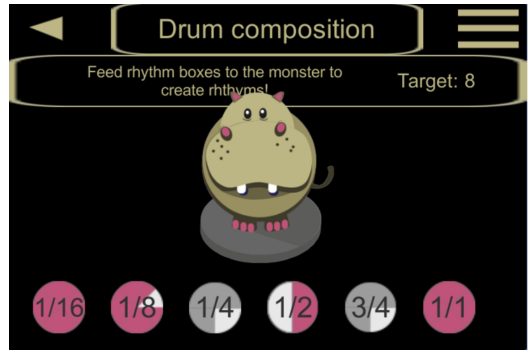

Figure 2: Rhythm composing in version 0.2

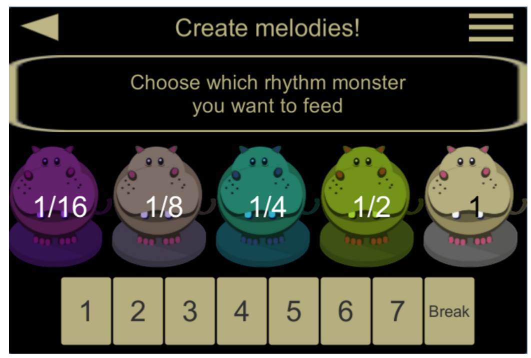

Figure 3: Melody composing in version 0.2

worked with Pääskyvuori school, a primary school in Turku, Finland. There we formed a co-design group with teachers and students to better integrate our application into the real learning environment, and to ensure that the application could be utilized in teaching. Rochelle and Peunel show how co-design has been utilized in creating innovations in educational materials, and describe seven key components required for successful co-design [14]. We used this information in planning the co-design components of our research.

IV. Design Process and Results

Before beginning the co-design phase, we created a pilot version (v0.1) of our application with the Unity3D game engine based on the knowledge we had gathered. We implemented a rhythm composing scene, where the user drags and drops rhythm notes to form an arithmetic calculation. We hypothesized that composing rhythms this way would force students to learn the relationship between music, fractional numbers, and decimal numbers. Figure 1 shows the rhythm composing scene of v0.1. The rhythm boxes can be seen at the bottom, and the target area is above them. The current calculation number is displayed on the right, and the target number or the number of beats is shown on the left.

The first co-design and testing phase took place in December 2016 at Pääskyvuori school, where we asked 6 students (M=4, F=2) and 2 teachers for free form feedback about the pilot version. We wanted to know whether students realized the connection between the arithmetic calculation they created and the resulting rhythm they heard. We gave the participants as little guidance as possible and documented all the ideas and improvement suggestions that emerged.

First phase results indicate that none of the students were able to imagine nor plan the kinds of rhythms they were creating, but they suggested several improvements:

- A better visual look;
- A clearer interface;
- Show the whole rhythm calculation on screen;
- The option to undo 'a move';
- Some kind of a tutorial or instructions;
- Ability to save and load songs;
- Ability to name own songs; and
- More instruments to choose from, not only the drum

Additionally, the teachers suggested these improvements:

- Replace boxes with fraction pies to help students visualise fractions; and
- Allow students to compose multiple beats and combine them to create more complicated rhythms

In the next design science cycle [8] we focused on two features: melody composition and better visual look. Additionally, we implemented the option to reverse calculation steps and a bar that shows the whole rhythm calculation. Figures 2 and 3 show the application v0.2.

In the second co-design cycle in January 2017, we asked the participants to test the application again for 15 minutes each. This time we primarily focused on the melody composition scene (Figure 3). All 6 students said the user interface and usability were improved. Whereas in the first testing phase every student had 2 or more improvement suggestions to the application, now half of the students had no improvement suggestions. However, one student suggested 5 improvements, the same as last time. Additionally, students seemed interested in continuing using the application in the second test phase, whereas in the first tests they showed little interest for continuous use. Here is a full list of unique improvement suggestions from the students:

- More instruments;
- Record singing together with a created soundtrack;

- Saving and loading songs;
- Customizable hippos, the option to use another animal;
- The option to change the beat length;
- A way to follow the created melody better; and
- More melody notes to choose from.

When the students were asked which feature they felt should be implemented to the application next, 4 out of 6 students said 'adding new instruments'. However, the student who suggested the most changes, said that being able to save and export songs was most important. The one remaining student wished for a way to follow the created melody better.

Teacher feedback was positive, and we received one unique improvement suggestion: change the music scale in the melody composing scene from a major scale to a pentatonic scale, because that scale is more likely to sound harmonious, or let the students choose which scale to use.

We also carried out a comparison test where we asked 21 4th grade students at Pääskyvuori to test both versions and compare their usability. 20 students said the new version was much better, and 1 student said it was mildly better.

V. Discussion

Our work exemplifies utilization of research design in creating educational software. The improvement between two test phases is shown by the data collected from co-designers and by the data received from the testing session with 4th graders. We believe that upgrading the user interface was the biggest impacting factor on why v0.2 was enjoyed by the students more than v0.1. We also observed that the 'more musical' melody composing scene was received better by the students than the rhythm composing scene. This implies that students are able to enjoy and perhaps even understand the audio feedback, and not only the visual feedback. However, further testing is required to confirm this.

Our observations suggest that most students were not focused on the visible rhythm calculation on the screen, and none of their improvement suggestions included math-related features. Possible reasons for this are our limited time with the students and the lack of guiding questions.

In addition to developing the co-design cooperation further, we intend to analyze and evaluate the application ourselves by drawing information from our knowledge base [8], [9]. Further study on music education, math education and music theory could also lead to new design ideas.

VI. Conclusion and Future Work

More work is required on how to best teach students to think of music mathematically and how to incorporate mathematics in our application so that it would be purposeful and helpful in composing. We hypothesise that using our application will have the following learning benefits:

- Boosts the motivation for learning math and music;
- Strengthens students understanding of the relationships between decimal numbers and fractional numbers;
- Students learn to think of music mathematically;
- Students learn scales, rhythms and composing; and
- Provides students an easy to use tool for obtaining the satisfaction of creating their own compositions.

We will continue our co-design work at Pääskyvuori school. Based on the suggestions we received, we will next add more instruments, enable saving and loading songs, include the allow exporting created songs, and improve usability. We also plan to measure the application's educational value. For example, we intend to study the relationship between the student's emotions and the composed song, and design composing exercises where students are tasked to recreate simple songs with our application.

Acknowledgment

We thank students and teachers at the Pääskyvuori school.

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