Learning Music and Math, Together as One: Towards a Collaborative Approach for Practicing Math Skills with Music

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Abstract. In this paper we present a study that took place in an elementary school in Mexico. The study aimed to explore the use of a digital application for the design and orchestration of collaborative, game-based learning activities for STEAM and to study the impact of group formation with respect to students' background knowledge. In particular, our goal was to support students in practicing math skills using music in a series of workshops. The workshops took place in the form of a tournament where groups of students worked together to win sets of music and math rounds. We formed groups based on students' background knowledge in math and we explored the impact of group formation with respect to students' background knowledge on learning gains – as assessed in pre and post knowledge tests – and game score. The results indicate that homogeneous groups outperformed heterogeneous groups in terms of learning gains but heterogeneous groups achieved better results in terms of game score than homogeneous groups. The former does not confirm related research and it may suggest that the group formation impact on learning gains depends largely on the context. The latter may indicate the need for aligning the game objectives with learning goals in order to ensure that educational games indeed prioritize learning.

Keywords: Collaborative learning · STEAM · Group formation · Game-based learning · Math · Music

1 Introduction

The aim of this work is to explore how we can use music to support students in learning math. In particular, we focus on designing game-based, musical activities that engage K-12 (that is, from kindergarten to 12th grade) students in practicing basic math concepts, such as addition and subtraction.

Mathematics, along with science and reading, is one of the core knowledge domains periodically assessed by the Programme for International Student

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Assessment (PISA)[1] pointing out the need to ensure that elementary students will develop key math skills and logical thinking in order to equip them to be able to solve practical and complex mathematical problems in the long term. Educational research argues that traditional teaching approaches and instructional methods for mathematics curricula do not have a positive impact on students [1,15]. On the contrary, learning experiences that are not based on traditional teaching approaches for mathematics curricula can contribute to bridging the achievement gap and to reducing mathematical anxiety [23]. For example, when arts are used as a vehicle for teaching we encounter several benefits such as: a) promoting communication among students, b) transforming learning environments, c) reaching out to students that otherwise may not be reachable, d) offering new challenges to students, e) decreasing curricula fragmentation, e) connecting in-school learning with real-world, among others [10,12].

A literature review on the relationship between music and math performance [25] showed that there was only a small positive association between the two topics and no solid evidence that music enhances math performance. However, this literature review mainly focused on whether musical performance relates to math performance rather than using music as an instructional tool for teaching math. On the other hand, [20] employed a game-based learning approach that engaged students in a mix of music and math activities. The results suggested that this approach encouraged students to draw conceptual relationships between mathematics and music, to critically think, analyze and solve problems and to be faster in carrying out learning tasks.

1.1 Research Objective

In this study, we follow up on the work of [20]. In particular, we study how we can support K-12 students in practicing basic math skills - such as addition and subtraction - by engaging them in game-based musical tasks. Furthermore, we explore how technology-enhanced collaboration can potentially support students' engagement and increase students' learning gains. To that end, we carried out a small-scale study in an elementary school in Mexico where we asked students to participate in a Music and Math Tournament for groups. During the tournament, a collaborative game-based learning app was used to orchestrate learning activities that engaged students in practicing collaboratively music and math skills. The results of this study suggest that students who participated in the activity along with team-mates of similar background knowledge achieved higher learning gains than students who participated in the activity with team-mates with different background knowledge. However, it was also shown that diverse student groups - in terms of students' background knowledge - were performing better in terms of game-play. The contribution of this work is twofold:

a. to contribute to research regarding the relationship between music and math in the context of Science, Technology, Engineering, Arts and Mathematics (STEAM) Education;

[1] https://www.oecd.org/pisa/.

b. to offer insight with respect to group formation for collaborative game-based learning contexts.

In the following sections we will provide a brief overview on related research regarding the combination of music and math in formal education and group formation for collaborative learning approaches. Then we will provide information about the methodological approach of this work and we will elaborate on the study set up. Next, we will present the analysis and results and finally we will conclude with a contextualized discussion on the findings, the limitations and the implications of this work.

2 Related Work

2.1 Music and Math in Formal Education

Research has indicated potential links between musical concepts such as melody, rhythm, intervals, scales, and harmony, with mathematical concepts such as integers, numerical relations, arithmetical operations and trigonometry [4,14]. Furthermore, research has been exploring the physical effects music has on the human body. For instance, music relates to very primal parts of the brain [16] and it affects cognitive processes such as attention and engagement [6,26]. Several studies have focused on different ways in which music can be used as an element to improve mathematical performance.

Vaughn [25] conducted a meta-analysis from published studies on the relationship between music and mathematics. The focus of the literature analysis was to explore three questions: 1) Do individuals who voluntarily choose to study music show higher mathematical achievement than those who do not choose? 2) Do individuals exposed to a music curriculum in school show higher mathematical achievement as a consequence of this music instruction? and 3) Does background music heard while thinking about math problems serve to enhance mathematical ability at least during the music listening time? The analysis suggested that there was a small positive association between the voluntary study of music and mathematics achievement, a minor causal relationship that music training enhances math performance and that there was no solid evidence that background music enhances math performance. It is important to note that the studies used for the analysis were exploring the relationship between music and math performance and not the use of music as a means for practicing math.

On the contrary, research that focuses on the use of music as a teaching means for math, suggests that there are positive effects. Geist, et al. [13] described the power of music as follows: "Music brings order to disorder. Teachers can demonstrate patterns without using any materials". They conducted a study with 3 and 4 year old children at the Ohio University Child Development Center in Athens, Ohio, which showed that children who engaged in music-related activities were able to explain mathematical concepts using their musical experience as a medium. Conversely, children not exposed to lessons with music along with mathematics, had trouble recalling the math concepts when asked. An, et al. [2]

investigated the effect of combining music with regular math courses on elementary students' performance. The results suggested that music and math courses had a positive impact on students' math skills. In a similar vein, Rajić [20] carried out a study to explore how a game-based approach that brought together music and math may affect students' motivation and engagement of work. The study was conducted with children aged from 8 to 12 years old from two schools of Belgrade, Serbia. By surveys as an instrument with three levels of answers (not at all, partially or completely) it was found that a high percentage of students (between 70% to 80%) confirmed that the game encouraged them to connect content in mathematics and music, to analyze and solve problems, to be faster in work and think critically. According to Rajić, this practice can also influence and scaffold the development of students' cognitive skills.

2.2 Collaborative Learning and Group Formation

Collaborative problem solving, collaborative learning, and teamwork, are terms that have been echoing for decades. Roschelle and Teasley [22] defined collaboration as the construction and maintenance of a shared conception of a problem resulting from a co-ordinated and synchronous activity. A growing emphasis in state and national education systems is that they are shaping curriculum and instruction around problem solving, critical thinking, self-management, and collaboration skills [8]. For collaboration to happen, we need to carefully craft the conditions that will enable it: learning scenarios that require students to work together, communication channels that facilitate information exchange and the space and time for social interactions between students to emerge. One critical aspect to accommodate these social interactions is the dynamics that come into play when people form teams to achieve a common goal.

A common approach for group formation is based on the students' knowledge complementarity. The rationale is that students with complementary knowledge will benefit from collaboration since they will have to exchange information knowledge in order to carry out the common task. This group formation approach is followed by the Jigsaw approach [3] that is also applied for orchestrating activities, distributing resources and learning materials in CSCL settings [9,19]. A step further, Erkens et al. [11] investigated how knowledge-complementary groups react upon receiving awareness support regarding knowledge exchange.

Existing research shows that heterogeneous groups usually achieve better results than homogeneous groups despite the fact that students prefer to group with students with similar characteristics [5,24]. For example, Manske et al. [18] found that heterogeneous groups regarding background knowledge would achieve higher learning gains than homogeneous learning groups when practicing with an online inquiry learning platform that engaged students in online labs activities. Furthermore, research has explored the formation of groups with respect to students' personality traits. For example, heterogeneous groups in terms of extraversion is considered to be beneficial [17]. This has been also confirmed by Bellhauser et al. [24] who investigated group formation with respect to extraversion and conscientiousness. Their findings suggest that heterogeneous extravert groups and homogeneous conscientious groups demonstrate positive effects on students' performance. However, it is not clear what happens in the case both personality traits are manipulated at the same time.

In this work, we aimed to explore the impact of group formation with respect to students' background knowledge in a collaborative game-based setting and whether heterogeneous groups would benefit more than homogeneous groups.

3 Methodology

3.1 Experimental Setup

For the purpose of this work, we conducted a study in collaboration with an elementary school in Zapopan, Mexico. During this study, we carried out a series of workshops that aimed to support students collaboratively practice around basic mathematics concepts along with music. The workshops were facilitated by a digital app (MusicalMonkeys) that delivered the learning activities to the students. In total, 14 students (9 female and 5 male) from 4th grade (approximately 9 years old) participated in the study. A workshop was organized each week for 7 weeks in total, resulting in 7 workshops overall. The duration of each workshop was about 45–50 min and during the workshops, students were working in groups on different learning activities, as provided by the app.

3.2 Musical Monkeys

Musical Monkeys Fig. 1 is an educational game application designed by MusicMath[2]. The game app allows connecting client iPads (that is, iPads operated by student groups) to a server iPad which is controlled by the teacher. The potential of using one mobile device to support the student group – instead of providing one device to each member of the group – has been previously studied is a similar context for scaffolding collaboration [7]. The rationale is that students will coordinate, define roles, distribute responsibilities and plan their action around the device. Thus, the one device will enable them to work together. The game allows teachers to organize students in groups and play two different types of "rounds" or challenges to combine math and music concepts. This game-based collaborative activity can be related to the following characteristics of a STEAM approach[3]:

1. Students are active in the learning process by doing (in this case, playing);
2. Cooperation, collaboration, communication and creativity are promoted during the gameplay, since children are challenged to think collectively in order to solve puzzles and trivias that connect math problems to music rhythms and vice versa;
3. This game aims to promote students creativity to find, evaluate and try their own processes for answering the math and music rounds.

[2] www.musicmath.mx.
[3] https://www.edweek.org/tm/articles/2014/11/18/ctq-jolly-stem-vs-steam.html.

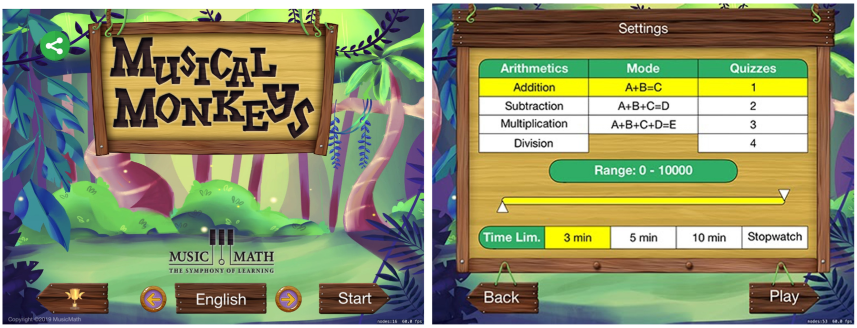

Fig. 1. Two screenshots from the Musical Monkeys interface: The welcome screen (on the left) and an example of setting up a math round activity (on the right)

The first round is called the "math round". This round is designed to engage elementary students in thinking and practicing with arithmetic concepts as an introduction to algebraic thinking. The latter is being presented as trivia, for example "2+? = 10" instead of "2 + 8 = ?". The math round allows practicing with four topics or math arithmetic operands: addition, subtraction, multiplication and division. During this round, student groups are called to answer randomly generated trivia exercises without the support of additional material (for example, pen and paper). The teacher can choose the difficulty level for these exercises and also set a time limit for the round in order to make the activity more challenging.

The second round is called the "music round". In this round, the app plays a musical rhythm to the student group and the group has to represent the rhythm as a geometric figure. To establish this representation, the students have to associate the rhythm beats to figure vertices. In other words, a musical rhythm that has 4 beats can be represented as a square or rectangle (4 vertices). Similarly, a rhythm with 5 beats will be represented as a pentagon, and so on.

3.3 Method of the Study

The study was carried out in the format of a *"tournament"*. We adopted this game-based approach with tournament rounds because we assumed that students would become more engaged in playing a competitive game based on problem-solving math problems rather than repetitively practicing them alone or in the classroom. Each round of the tournament was one workshop and was associated with either math or music rounds. The tournament started with a welcome workshop. There, the students had the opportunity to play a math and a music round in order to familiarize with the app. In this study, we wanted to explore the impact of these workshops on students' performance regarding math.

After the welcome round, we followed up with a math round where we administered a pre-knowledge math test. The structure of the pretest consisted of students playing individually a math round of the Musical Monkeys app. The task was addition in mode A + B = C, where the students were asked to calculate the value of B when A and C were given. The pretest consisted of five items and the duration of the pretest was five minutes. Each pretest item was awarded 0.2 points. Thus, the pretest score range was [0, 1].

Similarly, the tournament ended with a math round, where we administered a post-knowledge math test. Each student took the knowledge tests individually. For the rest four workshops (between the pre and post tests), the students played both math and music rounds. That is, for each workshop the student groups played 4 math rounds and 4 music rounds. Based on their performance, the team was awarded with a score at the end of each workshop. In this study, all rounds were similar in terms of difficulty (including the pre and post tests) and the scores for all rounds (pretest, posttest and workshop scores) work range from 0 to 1. For pre and post tests, the students were assessed individually and for the workshop rounds (week1 to week 4) the students were assessed as a group.

In order to explore the impact group formation might have on students' activity and learning gains, we divided students into two conditions: students who participated in the tournament as members of homogeneous teams (control condition, HM) and students who participated in the tournament as members of heterogeneous teams (experimental condition, HT). To form student groups, we used the students' scores in the pre-knowledge test. In this context, homogeneity refers to the background knowledge of students as this is assessed by the pretest.

Overall, two homogeneous groups were formed, each consisting of 4 students of similar background knowledge and two heterogeneous groups were formed, each consisting of 4 students with different background knowledge. When grouping the students into heterogeneous groups our goal was that the standard deviation of the pretest score per group would be high - indicating that the background knowledge of students was different. On the contrary, for homogeneous groups the standard deviation of pretest scores should be low. Additionally, we aimed to have a similar median pretest score per condition - so that the learning gains would be comparable. The details about the groups' pretest scores and formation is presented in Table 1. Our research hypothesis was that students of the experimental condition would show higher learning gains that the students of the control condition. As learning gain (LG), we define the score's difference between the posttest and the pretest (LG = Posttest Score - Pretest Score). To study the research hypothesis, we carried out a two-way, non parametric t-test (Mann Whitney U test). Furthermore, we carried out a descriptive analysis over time to explore patterns in the progress of students over the duration of the tournament regarding their performance in terms of gameplay.

4 Results

4.1 Descriptive Analysis

Overall, the students achieved on average 0.22 points on the pre-knowledge test ($Median_{pretest} = 0.2$, $SD = 0.2$). On the post-knowledge test, the students received on average 0.65 points ($Median_{posttest} = 0.6$, $SD = 0.28$). This shows that on average, there was a learning gain of 0.43 ($Median_{LG} = 0.4$, $SD = 0.17$). The results on the group level – that is the average and median pre and post tests scores and the gameplay scores for every group per week – are presented in Table 1. Almost all of the student groups improved their scores while playing the game rounds over time. Group 1 (HT) achieved the biggest improvement in terms of game score from week 1 to week 4 while group 4 (HM) showed no improvement in terms of the game score.

Table 1. Groups mean and median pretest and posttest scores and group scores during weekly gameplay reflecting groups' formation into heterogeneous and homogeneous with respect to their background knowledge

	Group 1 HT	Group 2 HT	Group 3 HM	Group 4 HM
Mean pretest score (SD)	0.47 (0.46)	0.47 (0.46)	0.20 (0.16)	0.25 (0.25)
Median pretest score	0.20	0.20	0.20	0.20
Week 1	0.5	0.75	0.6	0.7
Week 2	0.65	0.65	0.7	0.6
Week 3	0.65	0.55	0.6	0.7
Week 4	0.8	0.85	0.7	0.6
Mean posttest score (SD)	0.47 (0.31)	0.53 (0.42)	0.65 (0.34)	0.65 (0.25)
Median posttest score	0.4	0.4	0.7	0.6

4.2 Conditions Comparison

In order to be able to compare the two conditions with respect to the students' learning gains, we compared the students' prior knowledge as it was assessed by the pre-knowledge test. As aforementioned, the pretest, posttest and workshop scores ranged between 0 and 1. The average pretest score for students who formed homogeneous teams was 0.22 (sd = 0.2) and the average pretest score for students who formed heterogeneous teams was 0.47 (sd = 0.41). Heterogeneous teams marked 0.27 more than homogeneous teams (approximately double). This difference is mainly attributed to the high performers who were assigned to these teams in order to make them heterogeneous. This is also evident from the large standard deviation in the student groups' average pretest scores. Next, we compared the two conditions with respect to the median pretest score. The median pretest score for both students who formed homogeneous and heterogeneous teams was 0.2. A Mann-Whitney U test further indicated that there was no statistically significant difference between the pretest scores of the two conditions (at the $p = 0.05$ level). This finding suggests that the students of the control and the experimental condition had a similar background knowledge. Therefore, the two conditions can be compared in terms of learning gain.

Regarding the posttest, the average posttest score for students who formed homogeneous teams was 0.65 (sd = 0.28) and the average pretest score for students who formed heterogeneous teams was 0.5 (sd = 0.3). Similarly, the median posttest score for students who formed homogeneous teams was 0.6 and the median pretest score for students who formed heterogeneous teams was 0.4. However, a Mann-Whitney U test indicated that there was no statistically significant difference between the posttest scores of the two conditions (at the p = 0.05 level).

Then, we calculated the average learning gain, per condition. The average learning gain for students who formed homogeneous teams (control condition) was 0.43 (sd = 0.17) and the average learning gain for students who formed heterogeneous teams (experimental condition) was 0.03 (sd = 0.15). Similarly, the median learning gain for students who formed homogeneous teams was 0.4 and the median learning gain for students who formed heterogeneous teams was 0. A Mann-Whitney U test indicated that the learning gain was significantly greater for the students who participated in homogeneous teams (Median = 0.4) that for students who participated in heterogeneous teams (Median = 0) at the p = 0.05 level (U = 1, p = 0.037). These results are presented in Table 2.

Table 2. Individual student's results on the pre and post knowledge tests and learning gains

Student ID	Condition	Group	Pretest score	Posttest score	Learning gain
s7	HT	Group 1	0.2	0.2	0
s12	HT	Group 1	1	0.8	−0.2
s13	HT	Group 1	0.2	0.4	0.2
s1	HT	Group 2	1	1	0
s5	HT	Group 2	0.2	0.2	0
s14	HT	Group 2	0.2	0.4	0.2
s2	HM	Group 3	0.2	1	0.8
s4	HM	Group 3	0.4	0.8	0.4
s8	HM	Group 3	0.2	0.6	0.4
s10	HM	Group 3	0	0.2	0.2
s3	HM	Group 4	0.6	1	0.4
s6	HM	Group 4	0	0.4	0.4
s9	HM	Group 4	0.2	0.6	0.4
s11	HM	Group 4	0.2	0.6	0.4

4.3 Analysis of the Collaborative Activity over Time

Overall, we cannot identify a particular pattern in groups' gameplay scores over time (Fig. 2). It seems that heterogeneous groups managed to improve their scores over time while homogeneous groups scored the same points during the tournament. At the same time, even though heterogeneous groups achieved better scores for the tournament's final gameplay week (Week 4), they also had ups and downs in their game scores while homogeneous groups had a steady performance. The uneven performance over time could be an indication of the groups' heterogeneity and a result of in-group dynamics: one could hypothesize that when the high-performers take over the activity then the group achieves higher scores. However, in order to investigate deeper into this we would need to observe the groups' practice for long periods of time and in detail.

From the analysis, it is also evident that the gameplay scores do not reflect the performance of students in terms of learning gains. For example, Group 1 that achieved the highest gameplay score on Week 4 and the biggest improvement over time regarding gameplay, also demonstrated no learning gain (on average) regarding the pre and post knowledge tests. Similarly, Group3 scored similarly on every week of gameplay but demonstrated the highest learning gain regarding the knowledge test.

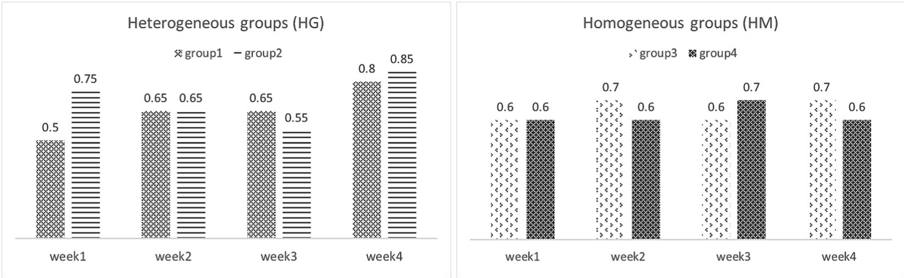

Fig. 2. Weekly game score over the duration of the tournament for heterogeneous (left) and homogeneous (right) groups

5 Discussion

The results of this work suggest that students who participated in the tournament as members of heterogeneous groups had lower learning gains than students who participated in the tournament as members of homogeneous groups. However, heterogeneous groups outperformed homogeneous groups with respect to game score during gameplay. Heterogeneous groups scored higher during the tournament rounds than homogeneous groups and they improved their performance from the first to the last round of the tournament to a greater extent.

On the one hand, this does not confirm related research findings that show that students from heterogeneous teams tend to demonstrate higher learning gains than students from homogeneous teams as demonstrated by Manske, et al. [18]. However, Manske, et al. studied the impact of groups' homogeneity for collaborative learning activities in the context of online labs. Our findings could suggest that the dynamics of collaboration have a different impact on learning gain depending on the collaborative context. For collaborative game-based learning activities, students' coordination is more important than communication and information flow. In collaborative problem solving, students have to establish a common ground and build knowledge in order to carry out the learning activity. In our study, students had to coordinate and use their background knowledge in order to achieve the game's objective. Therefore, it might have been easier for students with similar background knowledge to coordinate and craft a plan of action based on their existing domain knowledge. On the contrary, heterogeneous groups would not prioritize bridging the knowledge gap and establishing common ground but instead, they might have relied on the high-performing members to lead the activity in time in order to beat the game. This would consequently mean that the low-performing members of heterogeneous groups would neither gain new knowledge nor practice their math skills.

Another potential interpretation of the results may be that the game activities are not well aligned with the pre and post knowledge test items or that the game rewards points for game strategies the students' develop instead of actual knowledge. Therefore, achieving a high score in the game, does not indicate that the students also achieved the learning goals.

5.1 Theoretical and Practical Implications

We envision that this work has two main implications. On the one hand, it provides insight with respect to group formation for collaborative game-based learning for STEAM Education. Our findings suggest that the learning setting may potentially affect the criteria we use when forming student groups. Therefore, we may need to establish alternative criteria for group formation depending on the context.

On the other hand, our study emphasizes the importance of the design of the game activity regarding learning objectives. Educational games are considered a fun way to deliver learning experiences and to instigate children's interest, enthusiasm and curiosity [21]. Nonetheless, it is critical to prioritize learning when designing game-based learning activities and to ensure that carrying out the game's objective presupposes that the students have achieved the learning goals.

Finally, this work provides a practical example on the use of technology for orchestrating collaborative learning activities for STEAM. In this case, we used technology - in the form of a game application for tablets - to set up a music and math tournament. The teacher was able to have full control of the activities in terms of timing and difficulty while the students would engage with music and math activities in a fun and challenging way. Overall, the teachers and students who participated in the tournament were positive regarding this experience and they expressed their willingness in repeating the activity.

6 Conclusions

One of the challenges of modern education is to provide technology-enhanced learning experiences that can improve students' performance and to scaffold the acquisition of high-order skills such as creativity, critical thinking, problem solving and collaborative skills along with curriculum-based knowledge. The aim of this work was to explore the use of a game-based application for the orchestration of collaborative STEAM activities. In particular, we used Musical Monkeys to organize a tournament with music and math activities for groups of elementary (4th grade) students. Student groups were characterized as heterogeneous and homogeneous with respect to students' background knowledge, as assessed by pre-knowledge tests. The findings suggest that homogeneous groups demonstrated higher learning gains regarding domain knowledge (math) than heterogeneous groups. However, heterogeneous groups outperformed homogeneous groups in terms of game score. This points out the need for careful design of game-based learning activities in order to ensure on the hand hand that gameplay achievement relates to learning gains and on the other hand the meaningful collaboration and knowledge exchange between students.

We acknowledge that this research has some limitations such as the small number of participants and the lack of qualitative information, for example information regarding students' satisfaction. Another limitation is that students' collaboration is happening "offline", meaning that we cannot track the practice of individual members of groups through the application but we would need to rely on observations during gameplay. Furthermore, in this work we did not consider teachers' perspectives. In the future, we plan to expand our research towards two directions: on the one hand we aim to engage teachers into creating music and math learning activities in order to ensure that practicing skills using the game-based apps leads to learning gains. Additionally, we plan to integrate an intelligent virtual agent that will track students' progress and modify gameplay accordingly. On the other hand, we want to organize music and math workshops in the form of tournaments in a systematic way in order to be able to track the impact of these workshops on a wider scale and over time.

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