Interactive Music Science Collaborative Activities

Team Teaching for STEAM Education

Deliverable 6.2
Interim report on teacher's feedback and pilot testing in schools (A-Cycle)

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Executive Summary

This document presents the results of pilot testing Phase A (October 2017- December 2017) in relation to the:

a) technical usability and acceptance of the iMuSciCA learning environment, and
b) pedagogical fit and value of the iMuSciCA learning environment and educational materials,

as perceived by 35 teachers in total. Regarding (a), the present report complements deliverable *D5.6 - First Version of Usability validation of iMuSciCA toolkits*, which presents the technical usability validation of the iMuSciCA activity environments as perceived by students in Greece, France and Belgium.

Concerning the technical usability and acceptance of iMuSciCA learning environment, the findings from 16 teachers' answers to questionnaires for 6 iMuSciCA activity environments indicate that teachers found them overall easy to use and engaging. The latter was evidenced by the fact that they gave concrete and considerate suggestions about how the tools could be improved and further developed.

Similarly, 19 teachers in Greece and Belgium appreciated iMuSciCA's pedagogical framework and four of its educational scenarios, recognised their pedagogical fit and value and expressed confidence about their potential use in the classroom.

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TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Description
PU	Public Report
WP	Work Package
ATHENA	ATHENA RESEARCH AND INNOVATION CENTER IN INFORMATION COMMUNICATION & KNOWLEDGE TECHNOLOGIES
UCLL	UC LIMBURG
EA	ELLINOGERMANIKI AGOGI SCHOLI PANAGEA SAVVA AE
IRCAM	INSTITUT DE RECHERCHE ET DE COORDINATION ACOUSTIQUE MUSIQUE
LEOPOLY	3D FOR ALL SZAMITASTECHNIKAI FEJLESZTO KFT
CABRI	Cabrilog SAS
WIRIS	MATHS FOR MORE SL
UNIFRI	UNIVERSITE DE FRIBOURG

1. Introduction

This document presents the results of Pilot testing phase A (October 2017- December 2017) in relation to the:

a) technical usability and acceptance of the iMuSciCA learning environment, and

b) pedagogical fit and value of the iMuSciCA learning environment and educational materials, as perceived by teachers.

Regarding (a), the present report complements deliverable *D5.6 - First Version of Usability validation of iMuSciCA toolkits*, which presents the technical usability validation of the iMuSciCA activity environments as perceived by students in Greece, France and Belgium.

2. Methodology

2.1 Technical usability and acceptance of the iMuSciCA learning environment

The usability testing of the first version of the iMuSciCA learning environment aimed to guide the user-centered development process of the iMuSciCA prototypes. It involved both types of user groups, i.e. teachers and students and the test goals were related to the user experience and the examination of certain features of the activity environments (AEs) of the iMuSciCA workbench. In particular, the usability testing evolved around specifically designed tasks for the following AEs:

1. 3D Musical Instrument Design;
2. 3D Musical Instrument Performance (Leap Motion);
3. 3D Musical Instrument Performance (Kinect Guitar);
4. Drawing Canvas for Music Creation;
5. Geometry and Algebra Tools; and
6. Sonification of Mathematical Equations.

For each of these AEs, the corresponding technical partners, in collaboration with the project's pedagogical partners, developed scenarios of use with specific tasks for the user to carry out. These tasks were intended to allow the user to explore a number of interface and functionality aspects of the environment, so as to detect their strengths and/or weaknesses. The scenario of use for each environment can be found using the following links (localised translations for French, Belgian and Greek were also prepared - available upon request):

1. 3D Musical Instrument Design Activity Environment - Usability Testing Scenario:
https://docs.google.com/document/d/1G27Dx4LmJYA8C9pcP1i1kBfQUfHW-t-hqa77plh0XOE

2. 3D Musical Instrument Performance (Leap Motion) Activity Environment - Usability Testing Scenario:
https://docs.google.com/document/d/1-uKIKPzhLOEsUK7T5PpFcKwvJiiTElzc4iYJFCYpXio

3. 3D Musical Instrument Performance (with Kinect) Activity Environment - Usability Testing Scenario:
https://docs.google.com/document/d/1tM-JDXwQ_YsQqvd_vu4eyfPgwdO5KP3YSg_VMirBIpY

4. Drawing Canvas for Music Creation Activity Environment - Usability Testing Scenario:
https://docs.google.com/document/d/1XtOv6zG7CnppZ5EQ6iK8Ow0jPXOOouVyeJOarTFIQEo

5. Geometry and Algebra Tools Activity Environment - Usability Testing Scenario:
https://docs.google.com/document/d/1tFHa89M1zCY8F4i6iXhQoRMas-rmNg8Ks7dwp6ranWI

6. Sonification of mathematical equations and geometric curves Activity Environment - Usability Testing Scenario:
https://docs.google.com/document/d/1FUkMHS-0p6Yjnew-trOARWRWv9gH-CTFTHjScuX3F30

After carrying out the tasks described in the scenario for each of the activity environments, the users had to fill in a questionnaire, which contained closed Likert-scale type questions as well as space to write their comments regarding their experience with the environment. Teachers in particular had also to complete a general questionnaire with information about their background and experience in using ICT applications in general and in their classroom.

This general questionnaire and the questionnaire for each environment can be found using the following links (again, localised translations for French, Belgian and Greek were also prepared - available upon request):

1. General Teacher Questionnaire:
https://docs.google.com/forms/d/1NDFeQhduMpIqN-1AcEPoq9JvtOIfQeUDS_4jdaDK5KA

2. 3D Musical Instrument Design Usability Testing Questionnaire:
https://docs.google.com/forms/d/1J_IP-HzY-5pdBWLYzJSn9Uzy01rj0mZGaZdmupV9QUE

3. 3D Musical Instrument Performance (Leap Motion) Usability Testing Questionnaire:
https://docs.google.com/forms/d/1gj8JfJOTvN4AK6txXLei0j0h_L11BQa7HYvoFyUV6V4

4. 3D Musical Instrument Performance (Kinect Guitar) Usability Questionnaire:
https://docs.google.com/forms/d/1OZabReWcyJUHFbT-K80cCsRg699DFI-FmI5HZDfH8ws

5. Drawing Canvas for Music Creation Usability Questionnaire:
https://docs.google.com/forms/d/1Uy5dsmJdGio-BNPPVhvNh18oWpJdHuGL9-CWpnbLc8E

6. Geometry and Algebra Tools Usability Questionnaire:
https://docs.google.com/forms/d/1F1KkhJlXI6Vcu2oKu3MkfApWOs5WrRgr93_t9lDH9sA

7. Sonification of Mathematical Equations Usability Questionnaire:
https://docs.google.com/forms/d/1UirOAZPhS71MucTR4Ag2yK7GNR3KvUxigFpKPL2qHPo

In addition, researchers of the iMuSciCA project who facilitated this process, kept notes of the challenges the users met in their interactions with the environments. These notes provided extra qualitative information and feedback.

As previously mentioned, this deliverable is concerned with the teachers as users and presents the results of their usability questionnaires, whereas D5.6 presents the results of students' usability questionnaires.

2.2 Pedagogical fit and value of the iMuSciCA learning environment and educational materials

According to the Pilot Testing Action Plan (D6.1), and based on the initial pedagogical framework and iMuSciCA use cases described in deliverable D2.1 and the initial evaluation criteria defined in deliverable D2.2, teachers in the three partner countries should be introduced to the STEAM pedagogy and asked to give their feedback on the initial educational scenarios and lesson plans of iMuSciCA (proposed in D2.3).

The aims are to:

- familiarize teachers with the aims of the STEAM pedagogy;
- assess the pedagogic value of the proposed learning environment and related educational materials (e.g. scenarios and lesson plans); and
- customize the proposed educational materials to teachers, their students and their curriculum.

The process of this introduction was planned to start during Pilot Phase A (October-December 2017) and intensify in the preparation for Pilot Phase B period (January-March 2018).

To gauge teachers' reactions about iMuSciCA's pedagogical framework and specific scenarios or lesson plans a questionnaire was developed. This contains:

- 8 questions about teachers' background and previous experiences with teaching, using ICT applications in the classroom and connecting the teaching of STEM and Music;
- 3 questions about aspects of iMuSciCA's pedagogical framework, including the inquiry-based and interdisciplinary approaches promoted by iMuSciCA;
- 8 questions about the overall relevance, usability and learning value of iMuSciCA's pedagogical scenarios or lesson plans; and
- 3 questions about each of a maximum of two scenarios or lesson plans, that teachers had the opportunity to examine more in depth.

The latter two categories of questions combined Likert-type questions with open-ended questions requesting either written justifications for the corresponding quantitative answers given, or concrete suggestions about the strengths and weaknesses of the examined scenarios/lesson plans.

The questionnaire can be found, following the link below (again, localised translations for French, Belgian and Greek were also prepared - available upon request):

https://docs.google.com/forms/d/1J4KU2oAXLAeAYoIMYBeGAgzEIJXm7xgeejJFNjx1sUc

3. Implementation

3.1 Technical usability and acceptance of the iMuSciCA learning environment by teachers

Technical usability tests of the iMuSciCA 6activity environments were conducted with teachers in Greece, in a workshop which took place on October 21st, as part of the international 'Open Schools

for Open Societies' EDEN conference, organized by Ellinogermaniki Agogi at its premises.

The general setting involved two rooms. One room was equipped with 4 workstations (PCs of high speed CPUs, GPUs, with Leap Motion sensor devices) and 16 laptops (of lower speed CPU, without GPUs and memory). In the other room we had set up two workstations; one for the interaction with the Kinect and one for the recording of sensorial data during the use of the iMuSciCA activity environments. All PCs and laptops were equipped with headphones so that the users could hear clearly the sounds produced by the different environments.

The workshop lasted in total 3 hours, divided in two sessions of 1.5 hours each with a 0.5 hour break. In the first 0.5 hour, a general presentation on the iMuSciCA project and its pedagogical approach followed by a brief presentation of the various activity environments and tools. The rest 2.5 hours were devoted to hands-on experience. Teachers could work on the activity environments by moving around between laptops and desktops which were equipped with the Leap motion sensors.

There were in total 5 persons supervising the teachers working on the laptop and desktop workstations and 2 persons in the other room for the Kinect performing activity and the sensorial recording workstation.

Table 1 below shows by the number of questionnaires collected for each of the activity environments.

Learning Environments	**No of Questionnaires**
General Questionnaire	16
3D Musical Instrument Design Activity Environment	13
3D Musical Instrument Performance (Leap Motion) Activity Environment	12
Drawing Canvas for Music Creation Activity Environment	14
Geometry and Algebra Tools Activity Environment	16
3D Musical Instrument Performance (with Kinect) Activity Environment	11
Sonification of Mathematical Equations and Geometric Curves Activity Environment	14

3.2 Pedagogical fit and value of the iMuSciCA learning environment and educational materials

Data about the pedagogical fit and value of the iMuSciCA learning environment and educational scenarios were collected in different ways in Belgium and Greece[1].

UCLL in Belgium organized a whole day training event at its premises, during which 17 teachers explored and gave feedback on two pedagogic scenarios: 'Sound and Tone' (lessons 1 and 2) and 'Standing Waves and Resonant Frequencies' (lessons 1 and 2). For both scenarios teachers performed the activities by themselves in groups of 2 or 3 with one laptop. 4iMuSciCA researchers and teacher educators together with 5 student teachers, first presented the project's philosophy,

[1] In France, this data collection will take place next term, in preparation for Pilot Phase B.

pedagogical framework, and activity environments, and then guided and helped the participating teachers in their explorations with the scenarios, when appropriate. They also noted down any feedback the teachers gave them about the scenarios in order to improve these.

The 5 student teachers, had been both actively involved in the development of the iMuSciCA lessons and scenarios and had piloted one of them ('Sound and Tone') in two different classes in one school (Agnetencollege) at the end of November and beginning of December. Therefore, they had not only seen that scenario, but also pupils working with it. So had the teacher of these classes, who was also present in the training. All other participating teachers had not seen the two scenarios before. 17 teachers in total completed the corresponding questionnaire.

The researchers in EA, in Greece, followed a different method. They met with teachers of different specialisms (mathematics, physics and music) coming from their school and the local Music School, on various occasions. They first met teachers in small groups, where they presented them the iMuSciCA learning environment and pedagogical framework. They then sent teachers the two scenarios that were most relevant to them ('Investigating the Monochord' and 'Let's hear Thale's Theorem') to read, and then met with them individually or in pairs for about an hour each time to discuss each of the scenarios in detail. In total 11 teachers had a chance to get acquainted with the two scenarios, 5 of whom gave their feedback in questionnaire form and 1 also in an extended interview.

4. Findings from analysis of results

4.1 Technical usability and acceptance of the iMuSciCA learning environment by teachers

The following sections present the findings regarding the usability and acceptance of the iMuSciCA learning environment by teachers in Pilot Phase A based on the analysis of the corresponding questionnaires for the six activity environments and the observation notes drafted by the facilitators, who assisted the teachers in carrying out the usability scenarios. The quantitative results of the questionnaires can be seen as graphs in **Appendix A**.

4.1.1 Profiles of the teachers

Out of the 16 teachers who took part in the usability tests 9 were secondary teachers with a STEM teaching specialism, 1 was a Music teacher, 4 were primary school teachers and 2 were secondary teachers of other fields.

Although, all of the teachers seemed to have some experience in using ICT and/or e-learning applications, more than half of them had little or no experience in using them in their classrooms and only few more than a third (37.5%) used them frequently or very frequently in teaching.

4.1.2 3D Musical Instrument Design Activity Environment

4.1.2.1 Description of the usability scenario

In the given usability scenario, the teachers were asked to experiment with the strings of a polychord and especially how the length of the string affect the sound. Apart from zooming, rotating the point of view and changing the size of the instrument, the teachers were asked to divide each string into two equal parts by moving the bridge and verify that the sound produced by the two parts is the same. In a similar manner, the teachers had to move the bridge of two strings to the same position and verify that the corresponding equal substrings sound the same. In addition, the teachers were asked to freely change the frequency of one string without changing its size (i.e. experiment with the material, thickness or tension of the strings).

4.1.2.2 General remarks from observations and analysis of the questionnaires

Most respondents reported ease of use and intuitiveness with manipulating the viewport, and ease with respect to instrument manipulations, even though most of them had no previous experience with such environments. Although the 3D Musical Instrument Design Usability Testing Questionnaire reflects the three-dimensional design of the monochord, the results highlight the potential for improvement of all virtual instruments foreseen. In teachers' first interaction with the environment's functionality to change the structural characteristics of a sounding object, 83% of them reported that the produced sound was pleasant and in line with their expectations. The challenge of having two virtually separated strings sound in unison when all their fundamental resonant characteristics are equal, appears to be achieved by the environment.

Despite the moveable area of the instrument colored in cyan, difficulties where reported in finding the way to change the size of the instrument while being able at the same time to view the segment-lengths. Users also tried to manipulate the virtual-instrument sizes using their hands, especially in cases where the activity environment with the Leap Motion sensor had been tested before.

More than half of the respondents (58.3%) reported that they could produce similar sounds when requested to but not perfect unison, while the rest 41.7% reported that could perfectly match the request. As regards the different ways to produce different sound, a variety of answers were given. The teachers seemed to prefer more to change the material, tension or radius of the string, and less the instrument's length, or to move the bridge's position. Regarding the sound quality most respondents (a cumulative 66.7%) rated it as excellent or almost excellent, where a cumulative of 91.7% denoted it above average.

As an overall assessment of the 3D musical instrument design environment it is evident that it is built in a way that it allows further development of all the aspects the project is determined to meet.

4.1.3 3D Instrument Performance (Leap Motion) Activity Environment

4.1.3.1 Description of the usability scenario

The main task in the usability scenario was to try and evaluate two modes of interaction with the virtual string instrument: the free interaction mode and the gesture interaction mode. In addition, the teachers were also asked to experiment with the various features of the AE, i.e. by using tools and visualization, to explore other functionalities of the environment, such as the gesture interaction recorder and the audio recording tool.

4.1.3.2 General remarks from observations and analysis of the questionnaires

The musical instrument performance with the Leap Motion sensor is similar to the one with the Kinect sensor, but more focused on the detailed recognition of human hands' and fingers' movements. All of the respondents were unfamiliar with the Leap Sensor. Most of them (41.7%) also were not quite familiar with playing any musical instrument and only a 16.7% considered themselves musicians. The majority was neutral (50%) or appreciated the usability of the Leap Motion sensor (41.6% rated it as 4 and 5 in the 5-point scale), and responded positive about the overall appearance of the interface (91.6% rated it 4 and 5 in the 5-point scale). The free interaction mode was also much appreciated (50% rated it with 4 and 16.7% with 5). The quality of the produced sound was also highly appreciated (50% rated it with 4 and 25% with 5). The responsiveness of the tool was however less appreciated (only a total of 58.4% rated it 4 and 5). The use of the tuner satisfied the respondents by 33.3% whereas the rest of the teachers (66.7%) noted that only sometimes could they identify the notes produced with the help of the tuner. Some 58.3% mentioned that they could observe the different frequencies produced by the different strings in the 3D spectrogram control, a 25% stated that they could sometimes do that, while the rest (16.7%) stated that they could not do it at all. More than half of the respondents (58.3%) rated gesture based interaction with 4 and 5 (most of them 5), but half of them didn't find it easy to record gestures of their performance. Recording audio performance was certainly an easy task for 75% of the respondents.

According to the respondents' further consideration upon the images appearing at the sides of the screen should be given, since clickable features were expected. As mentioned for the 3D Instrument design environment, users that had done the activity of 3D musical instrument design were trying to find a way to modify the virtual instrument within the interaction environment. Listening to the continuous sonification of their fingers, users often got confused with the plucking function, thus triggering the generation of multiple sounds at the same time. Heavy fluctuations in the volume of the sonification are also noticed without following the nature of the gesture. Leap Motion for replacing mouse in the 3D instrument design manipulation and a computer touchpad instead of Leap Motion for triggering the sonification gesture was also suggested. Overall an overwhelming number of respondents consider the Leap Motion sensor as the key-device for engaging hand-recognition in a virtual environment.

4.1.4 3D Instrument Performance (with Kinect) Activity Environment

4.1.4.1 Description of the usability scenario

The tasks in the usability scenario for this activity environment were intended to reveal whether the users felt like they had control over the basic gesture scheme with an Air Guitar. Therefore, the teachers were asked initially to get acquainted with the gestures and then try to play all notes of the air guitar with different levels of intensities.

4.1.4.2 General remarks from observations and analysis of the questionnaires

Results from the Kinect interaction software and hardware show a positive attitude towards the functionality to produce audio with virtual instruments in combination with the use of hands and body, despite the fact that half of the respondents (54.5%) were totally unfamiliar with the Kinect sensor and also unfamiliar with the playing of any musical instrument. Nearly all respondents (90.9%) highly appreciated the usability of the Kinect sensor performance tool and they similarly responded about the excellence of the quality of the sound produced. More than half of the

respondents (63.7%) appreciated the responsiveness of the tool and the rest (36.3%) found it adequate. The use of the tuner for identifying the notes produced totally satisfied 72.7% of the respondents, whereas the rest (27.3%) noted that the tool helped them only partially. There was a similar finding about controlling the volume of the note. Overall the Kinect sensor proved to be a very useful tool in engaging users to interact with iMuSciCA's environment through the human body.

4.1.5 Drawing Canvas for Music Creation Activity Environment

4.1.5.1 Description of the usability scenario

The usability scenario for the Drawing for Music Creation AE asked users to draw specific shapes (e.g. a rectangle); listen to those shapes; listen to different timbres by changing the stroke color; find out ways to delete their drawings (by clearing canvas or deleting specific strokes); and "lock" the drawing canvas to specific frequencies (and then draw lines corresponding to given notes).

4.1.5.2 General remarks from observations and analysis of the questionnaires

Most teachers were satisfied about the ease of use of the environment and the amount of time it took them to complete the task. However, teachers needed support information when completing the task (see graph for Q5.1 in Appendix A.5). All respondents reported satisfaction and clear view of the GUI panes while the colour code for different timbres also worked fine for them as a GUI choice. The play button functionality also worked quite fine as GUI element for all respondents. A 57.2% of the respondents were unsure or had no clue as to "how the stick to line" option worked while sound visualization pane worked clearly for all the respondents. The pen erase button needs more visual elaboration, as most people were unsure or had no clue as to how it worked. More than half of the respondents noticed the three available views at the side of the screen, however GUI can be improved in becoming more visually prominent, as approx. 45% felt unsure or had no clue of the available different views.

Teachers feel better if text is included with the icons in the settings or there is a help button or an example as a guideline. Clearer indications about the tempo are proposed to be included as the relation between the progress of the spectrogram visualization on the right and the cursor tempo does not seem to be clear. The right-click erasing button was hard to find but the feature of erasing specific parts (not the whole sketch) was appreciated. An "undo button" that also explains that you can click on the line (not anywhere else) to erase specific parts would be useful while it was suggested that the colours should correspond to frequency in Hz. Support to draw outside the grid should also be considered since the line 'stopped' when attempted to follow the drawing. The 't=0' indication in the spectrogram is suggested to start from the left to the right, which would be more familiar to the students and a pause button would be optimal. The playing cursor is reported to stop unexpectedly sometimes while the 'lock to grid' selection seemed not to work for all lines, but only for half of them. Recording functionality was requested while the spectrogram view was suggested to be enlarged.

4.1.6 Geometry and Algebra Activity Environment

4.1.6.1 Description of the usability scenario

In the first task for the Geometry and Algebra Activity Environment the teachers were asked to draw a triangle, measure the angles of the triangle and validate that their sum is equal to 180 degrees by using the calculator tool. The second task involved the construction of two graphs (lines) and their

intersection.

4.1.6.2 General remarks from observations and analysis of the questionnaires

From the study of Geometry and Algebra tools questionnaire it is evident that half of the respondents haven't used dynamic tools of that kind before. Though 62.6% of teachers responded with 3 and 4 when rating the ease of using the tools, only 18.8% appreciated them fully. Half of the users found the piles to open the tools easily (6.3% found them very easy, while an equal percentage failed to find them easy at all). A 37.5% of the respondents did not notice that 3D tools were available at all, while an equal part to that used the 3D feature successfully and the rest 25% did not know the way to trigger it. The majority of 43.8% really enjoyed plotting graph functions while the rest did not notice that functions other than y=ax+b could be represented or took them a while to understand that any graph was obtained. Most people used tools from the point, line and curve piles.

Teachers also suggested improving the way the tool handles the rotation and calculation of angles without a mouse, since finding how to draw or measure an angle was not considered very easy. The numeric pad on the computer's keyboard was suggested to correspond to the calculator on the platform. The integration of the calculator in the Notepad was also suggested. A teacher did not find any true relation of the environment with music. Though different metric systems exist, a teacher could not see where these were. Overall the Geometry and Algebra environment is considered to be of utmost significance connecting the heart of deeper-learning activities with the actual design of a virtual object based on mathematical evidence. The second generation of iMuSciCA tools is determined to meet all usability improvements mentioned.

4.1.7 Sonification of Mathematical Equations Activity Environment

4.1.7.1 Description of the usability scenario

The usability scenario for the Sonification of Mathematical Equations tool directed the teachers to use the graph drawing area for creating basic shapes (i.e. line, circle and rectangle) and listen to their 'sounds'. The teachers were then asked to clear the graph area, open the math editor and 'handwrite' using the mouse a given mathematical equation, which they could afterwards visualise and sonify in the graph area.

4.1.7.2 General remarks from observations and analysis of the questionnaires

The sonification environment for graphs proved to be adequate with respect to the tasks that users needed to complete. All of the respondents found it (almost) very easy to complete the tasks. The same was the case for choosing the correct icons and sequence of the requested actions. A high majority (92.9%) stated that they were satisfied with the amount of time it took them to complete the study. A 84.6% found the use of the palm icon informative to hand-draw geometric shapes, whereas the use of the x^2 icon was also highly appreciated (more than 90%) as an open math editor icon. A 92.3% of the respondents also confirmed that the recognition engine was able to correctly transform the strokes into geometric shapes, and the same percentage also confirmed the correct recognition of strokes into the proper math equation.

The play button use was 100% accepted and showed clearly its intended use.

The relationship between the y-axis value and the frequency was also quite clear (84.6%), but the trash icon use was a bit less clear to the respondents (69.2% said it was clear). Further development

of the tool should be considered though users liked the connection between graphs and sounds. The issue of dots appearing after the correct recognition of an equation did not lead to a graph plot even though the equation was recognized correctly unless dots where clicked to disappear. The difficulty of drawing with the mouse or locating the “erase all” button should be considered as part of the tool’s agenda for further development along with possible highlight or colouring of the toolbar to facilitate the buttons’ location. Overall the sonification environment plays a significant role in facilitating the interaction between mathematical graphs and sound production. Further development of this element is expected to take place as the project progresses.

4.2 Pedagogical fit and value of the iMuSciCA learning environment and educational materials

4.2.1 Profiles of the teachers

Table 1 shows the profiles of the teachers that participated in the testing of a selection of the iMuSciCA scenarios.

Table 1: The profiles of the teachers that tested each of the initial iMuSciCA scenarios

iMuSciCA Scenario	Number of teachers	Teaching Speciality Distribution	Average Teaching Experience (years)	Average teacher experience in ICT	Average Teacher experience in connecting STEM with Music (1-4)
1. Sound and Tone	16	68,75% Science/Mathematics 18,75% Music 6,25% Technology 6,25 % other	50% > 10 years 12,5% between 5 and 10 years 37,5% <5 years	6,25% very experienced 93,75% relatively experienced	2,2
2. Standing Waves and Resonant Frequencies	16	62,5% Science/Mathematics 18,75% Music 6,25% Technology 12,5 % other	43,75% > 10 years 12,5% between 5 and 10 years 43,75% <5 years	6,25% very experienced 93,75% relatively experienced	2,2
3. Let's Listen to the Thales Theorem	3	100% Science/Mathematics	100% > 10 years	66,67% very experienced 33,33% relatively experienced	2,3
4. Investigating the Monochord	3	100% Science/Mathematics	100% >10 years	66,67% very experienced 33,33% not experienced	2

4.2.2 Preliminary findings about a selection of educational scenarios

The scenarios: “1. Sound and Tone” and “2. Standing Waves and Resonant Frequencies” were trialed with more teachers than the scenarios: “3. Let’s Listen

to the Thales Theorem" and "4. Investigating the Monochord". The majority of participant teachers were Science or Mathematics teachers with adequate average teaching experience which varied from scenario to scenario. The participant teachers were on average relatively experienced in the use of Information and Communication Technologies in the classroom with scenario-related variations. However, overall, the participant teachers appeared to have barely adequate experience in connecting STEM with Music in the classroom.

Table 2 presents the findings from the analysis of the teacher questionnaires about a selection of the iMuSciCA's educational scenarios.

Table 2: The findings of the teacher questionnaires on the educational scenarios implemented with teachers in Greece and Belgium.

Scenario	**#Trials**	**Rating (0-5)**	**Achievement of declared educational objectives (1-4)**	**Relevance to Curriculum (1-4)**	**Comprehension of iMuSciCA's pedagogical Framework (1-4)**	**Help to implement an interdisciplinary approach in the classroom (1-4)**	**Help to implement an inquiry based approach in the classroom (1-4)**	**Potential interest to students (1-4)**	**Potential to increase students' performance in STEM (1-4)**	**Potential Use in Class (1-4)**
Sound and Tone	16	4,1	2,9	3,4	3,5	3,5	3,7	3,75	3,4	3,6
2. Standing Waves and Resonant Frequencies	16	2,8	2,9	3,4	3,5	3,6	3,75	3,75	3,4	3,6
3. Let's Listen to the Thales Theorem	3	4,3	3	3	3,5	3	3	3	4	4
4. Investigating the Monochord	3	4,7	3,3	2,3	4	3,7	3,7	3,7	3,7	3,3
% Rating[2]		79	76	76	91	86	88	89	91	91

[2] This is the average of all means above, expressed as a percentage.

According to the findings from the teacher questionnaires, the implemented educational scenarios got an average rating of 79%. The declared educational objectives were found to be satisfied on average by 76% and the average relevance to the school curricula was rated to be of the order of 76%. The scenarios helped the teachers comprehend the iMuSciCA pedagogical framework by 91%. Consequently, the potential of the initial iMuSciCA scenarios to help teachers implement an interdisciplinary approach in the classroom was of the order of 86% and the scenarios' potential to help teachers implement an inquiry based approach in the classroom was found to be of the order of 88%. According to the participant teachers' estimates, the scenarios have an average 89% potential to interest their students and a 91% potential to increase the students' performance in STEM subjects, while they foresee a 91% potential to implement iMuSciCA scenarios in the classroom.

Overall, the first version of educational scenarios appears to be usable, to have achieved attracting the teachers' interest in iMuSciCA, presenting clearly the iMuSciCA pedagogical framework and with high potential to engage students and help them increase their performance in STEM related subjects.

The relevance to the respective school curricula is considered acceptable, taking into account the fact that the implementation of the iMuSciCA scenarios doesn't only take place in the framework of a classroom hour but also in the framework of student clubs specialized in project based learning. This also can be seen as a consequence of the innovative character of the iMuSciCA scenarios, as teachers are not used to interdisciplinary teaching and even less to STEAM teaching. However, in the framework of designing the intermediate version of iMuSciCA scenarios, these results should be taken into account and the scenarios should achieve higher relevance to the curricula in order to expand the reach of the iMuSciCA approach in more schools which may not be able to implement project based learning.

Taking into account the participant teachers' low experience in connecting STEM with music, as well as their average high teaching experience, the 76% overall achievement of the declared educational objectives in the implemented educational scenarios should be thoroughly investigated in a per-scenario basis. The authors of the educational scenarios are encouraged to pay special attention to express their educational objectives in the scenario metadata in a clear and accurate way. The language of the educational scenarios should be clear and the content of the scenarios should be better suited for the students of the age group declared in the scenario metadata.

The second generation of iMuSciCA scenarios is foreseen to be co-created by iMuSciCA experts along with high school teachers in order to achieve a better adaptation to the school curricula and a higher satisfaction of the declared educational objectives.
Table 3 summarizes the teachers' observations for each explored initial iMuSciCA educational scenario. Combined with the relevant quantitative indicators presented in table 2, we conclude that care should be taken in order to present the concepts on which the scenarios are based clearly, adapting them on the level of the students and using language which is familiar to them while focusing on the inquiry based approach. The high variety of tools developed by the iMuSciCA consortium has been successfully integrated in the individual educational scenarios and this affects the teachers' satisfaction in using an individual scenario. This feature should be enhanced further in a two-fold fashion: by integrating more iMuSciCA tools and by harnessing the maximum of each tool's potential.

Table 3: Positive aspects and improvement guidelines for the initial iMuSciCA educational scenarios.

Scenario	Positive aspects	Proposed improvements
1.Sound and Tone	● It is clear, well structured, constructive, the use of Cabri is very positive for the students, with good visual support, a lot of material and provides connections with real life. ● The illustration of new concepts is considered very good. ● It encourages self-directed learning and experiential learning and gives a good presentation of the musical aspect.	● The wording is sometimes confusing and needs better adaptation to the vocabulary that the students use. ● Questions that help students delve deeper in the scenario's contents are suggested. ● Clearer instructions on how to use the tools are recommended, as well as a deeper presentation of science concepts such as waves, is proposed. ● Questions and answers should be presented with more clarity.
2.Standing Waves and Resonant Frequencies	● The scenario is challenging, ● It helps the learner to deepen their knowledge on the presented topic. ● It is characterized by beautiful visualization, the extensive use of the possibilities provided by the Cabri tool, and the potential for students to test a number of things.	● A clearer transition between the different parts is recommended. ● As the concept addressed by the scenario is difficult to apply to junior high school students, the level and method of application of the scenario should be adjusted to the level of the pupils accompanied by clearer explanations and a more solid presentation of the purpose of the lesson.
3. Let's Listen to the Thales Theorem	● Well structured ● Inquiring ● Promoting and creativity and free choice ● Connecting graphs with music	● It needs to be more efficient and expressive. ● It lacks inquiry based questions. ● The connection between the tools and the scenario is not clear. ● It would be helpful finding a program that connects the results from CABRI with Leopoly.

4.Investigating the Monochord	● Instrument construction and interactivity using the 3D design environment are considered very strong points within the scenario. ● The students can be persuaded to investigate not only the musical instrument but also the theory of music. ● The scenario is enriched with inquiry based questions which can motivate the students both for STEM and music. ● It is very well suited to be taught in the framework of a mathematics lesson. ● The extra links for potential expansion are appreciated.	● The objectives should focus also on the mathematical content of the scenario. ● More mathematical concepts should be also present on questions. ● This scenario can be applied in a student club but not easily in the everyday mathematics lesson due to the fact that not all the mathematics functions addressed are examined in the 2nd year of high school curriculum as well as due to the fact that the tight schedule of the Greek high schools doesn't encourage such open activities.

Appendix B contains extracts from an interview conducted with a Greek mathematics teacher about iMuSciCA's environment and educational materials and gives some first insights about their pedagogic fit and value in a broader way.

As the iMuSciCA tools are still under development, it is expected that the second generation of iMuSciCA scenarios will achieve even higher satisfaction on behalf of the associated teachers and students.

Appendices

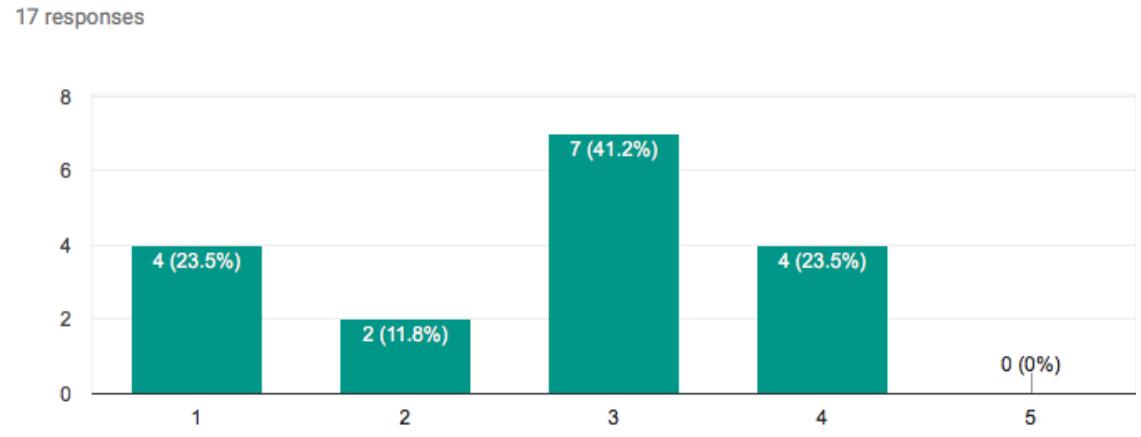
A. Quantitative Findings from the Usability Tests with Teachers

A.1 Teachers' profiles

Q1.1 Teachers' specialism

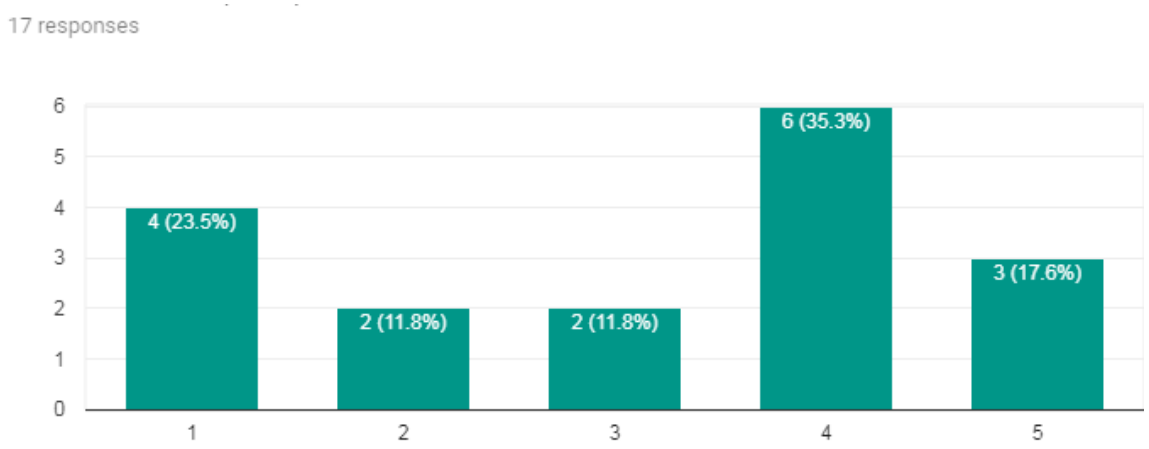
Teaching Specialism	#
STEM - related	9
Non-STEM related	2
Music	1
Primary School Teacher	4

Q.1.2 How experienced are you in using Information and Communication Technologies (ICTs) and/or e-Learning applications?



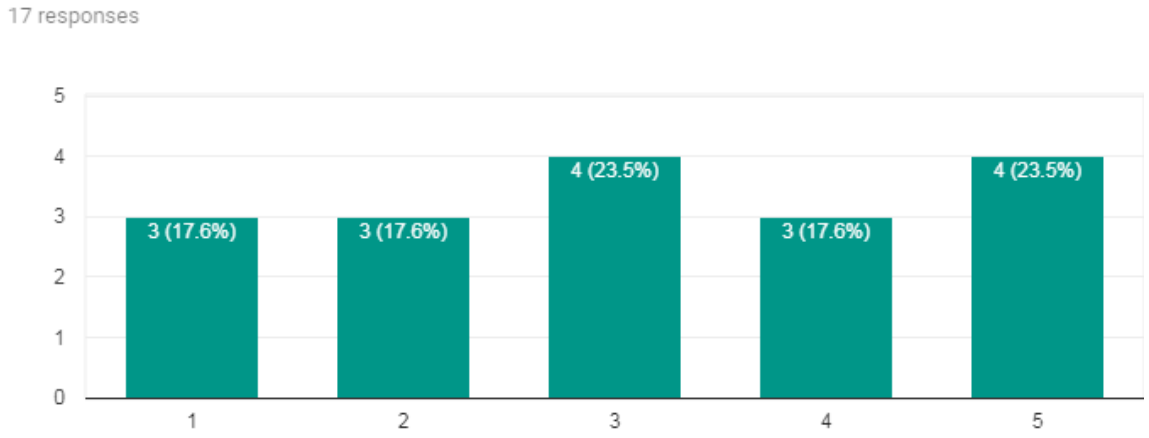
1: Very experienced – 5: Not at all

Q.1.3 How experienced are you in applying Information and Communication Technologies (ICTs) and/or e-Learning applications in your classroom?



1: Very experienced – 5: Not at all – N/A

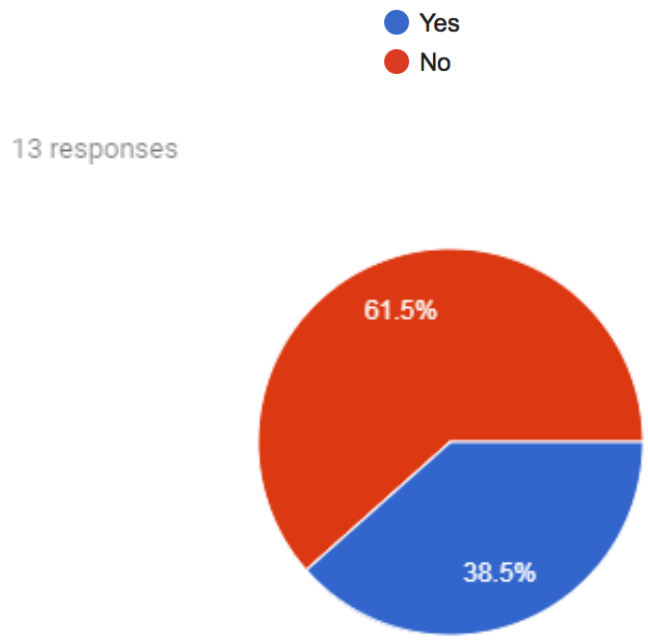
Q.1.4 How often do you use e-Learning applications in your classroom??



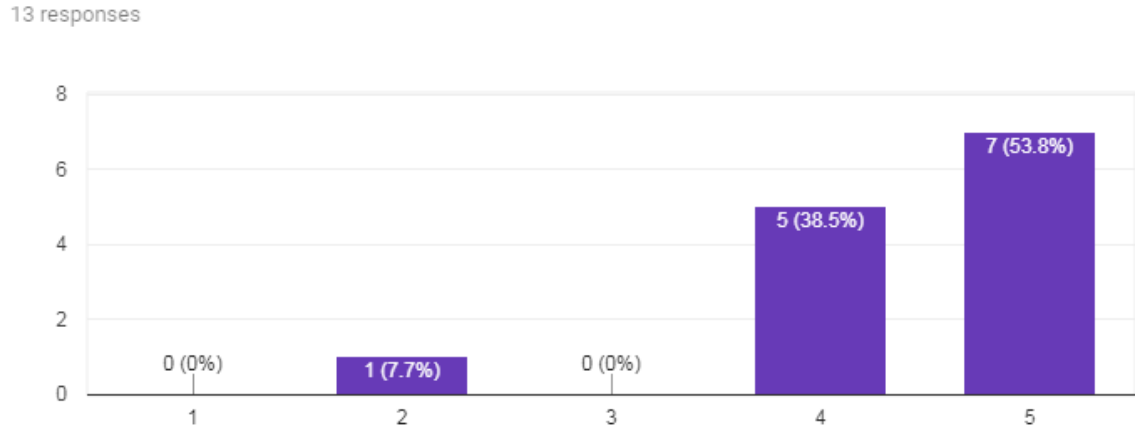
1: Very often – 5: Not at all – N/A

A.2 3D Musical Instrument Design Activity Environment

Q.2.1 Have you ever used any 3D design environment?

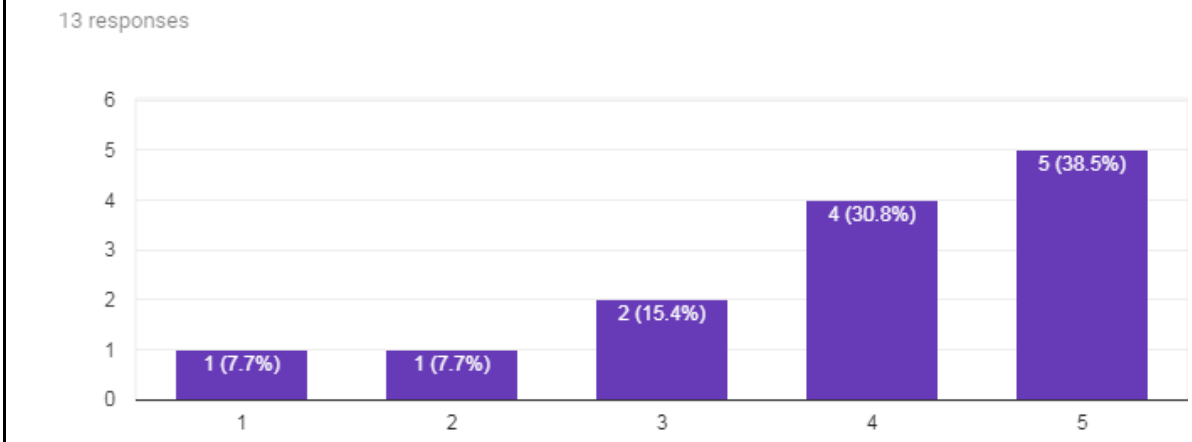


Q.2.2 How handy was the navigation (manipulating the viewport)?



1: Very hard to navigate - 5: Very easy and intuitive

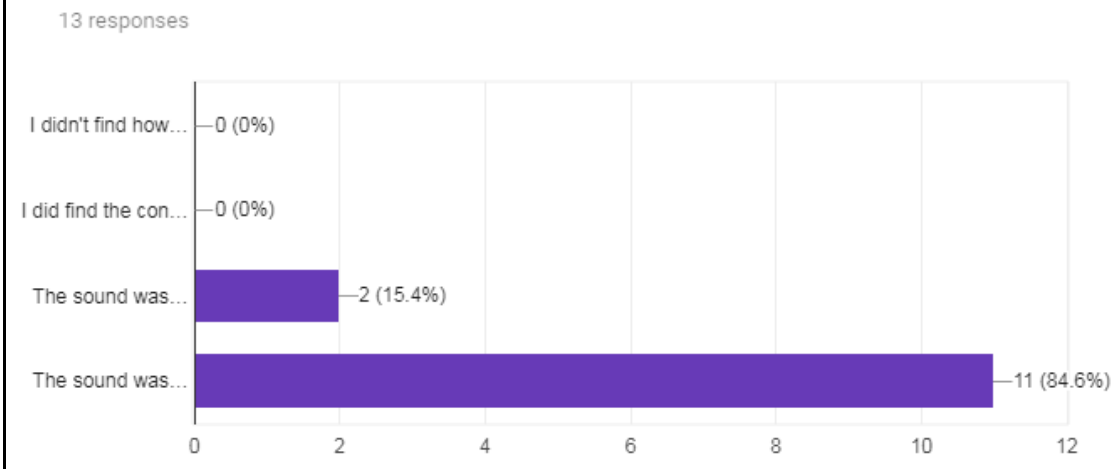
Q.2.3 Did you find the right parts to manipulate the instrument?



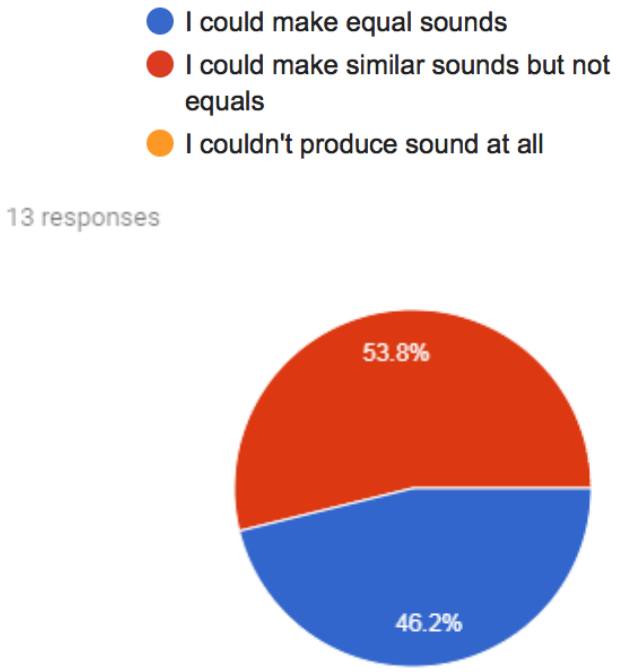
1: I could not find the appropriate parts - 5: It was very easy to find them

Q.2.4 Have you succeeded with the tasks related to tones?

- I didn't find how to make the sound
- I did find the control but I couldn't hear the sound
- The sound was not what I expected
- The sound was clear and in line with my expectations

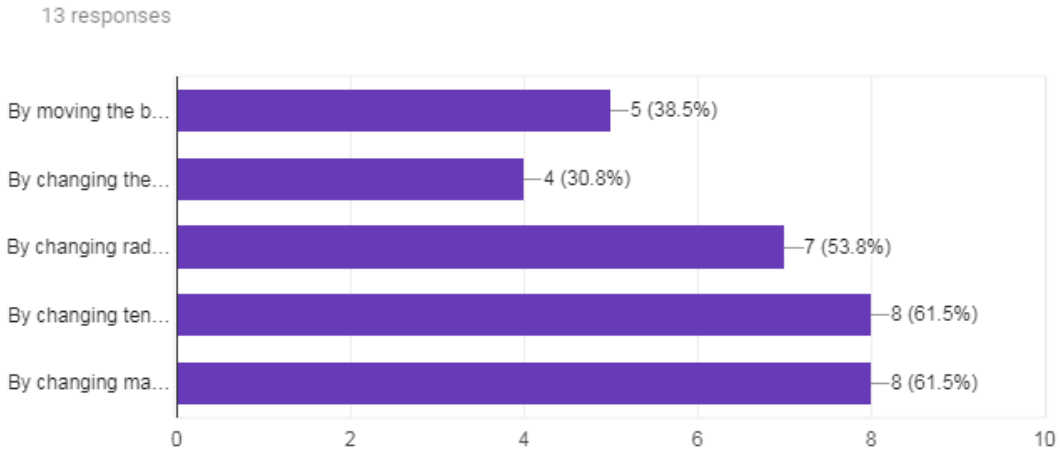


Q.2.5 Could you produce similar sounds when it was requested?

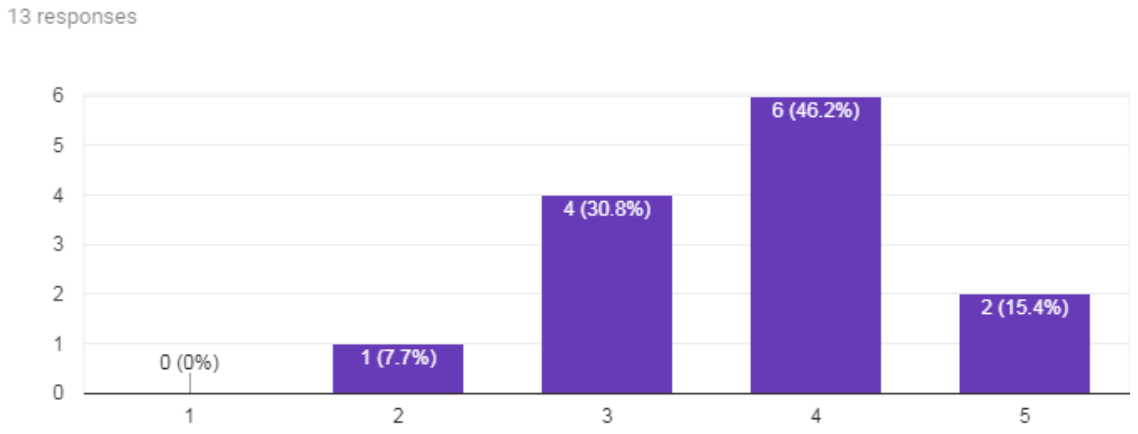


Q.2.6 How did you produce different sounds in the last step?

- By moving the bridges
- By changing the length of the instrument
- By changing the radius of a string
- By changing the tension of a string
- By changing the material of a string



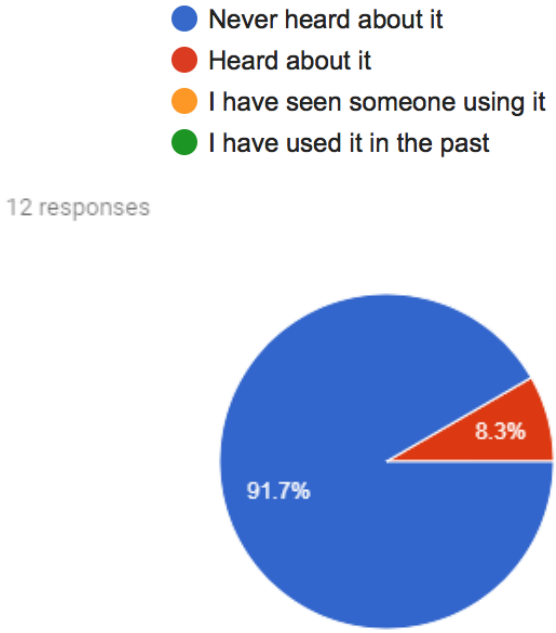
Q.2.7 How would you rate the sound quality of the instrument?



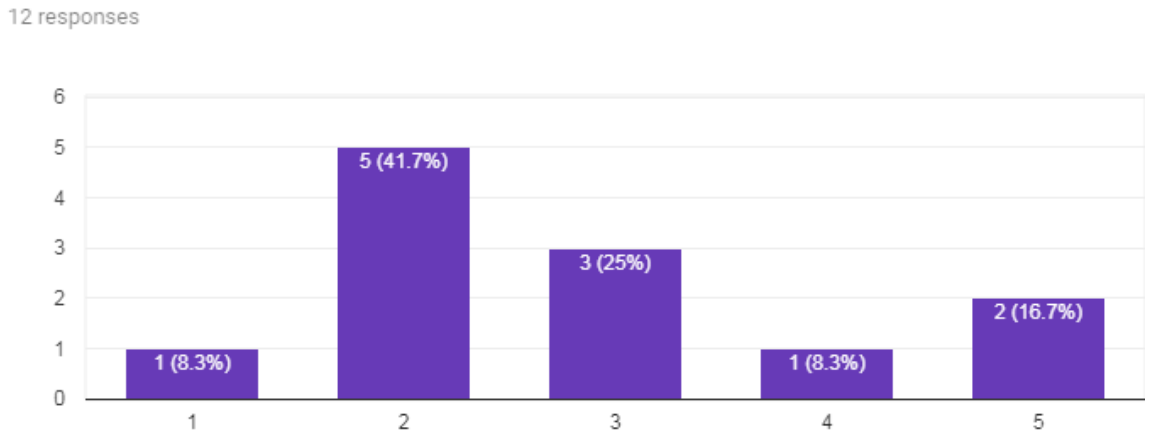
1: Poor - 5: Excellent

A.3 3D Musical Instrument Performance (Leap Motion) Activity Environment

Q.3.1 Did you know the Leap Motion Sensor?

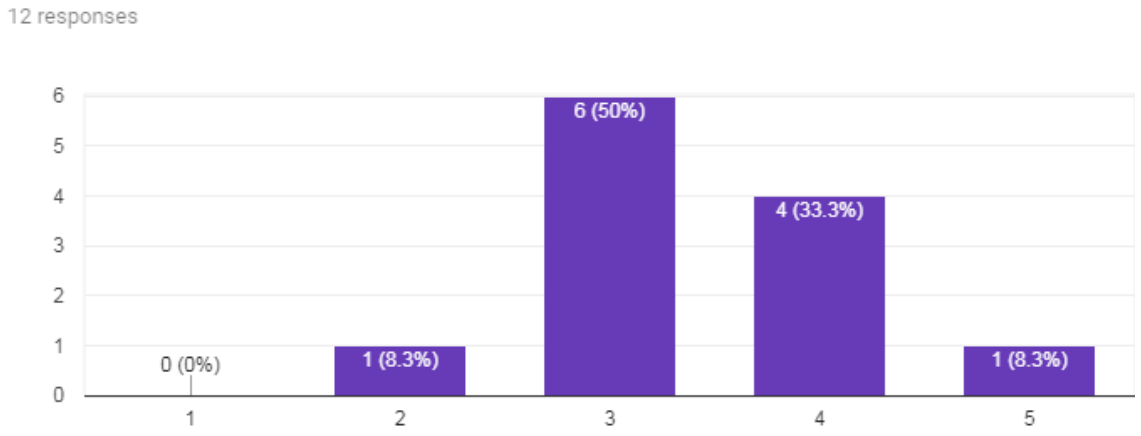


Q.3.2 How familiar are you with playing a musical instrument?



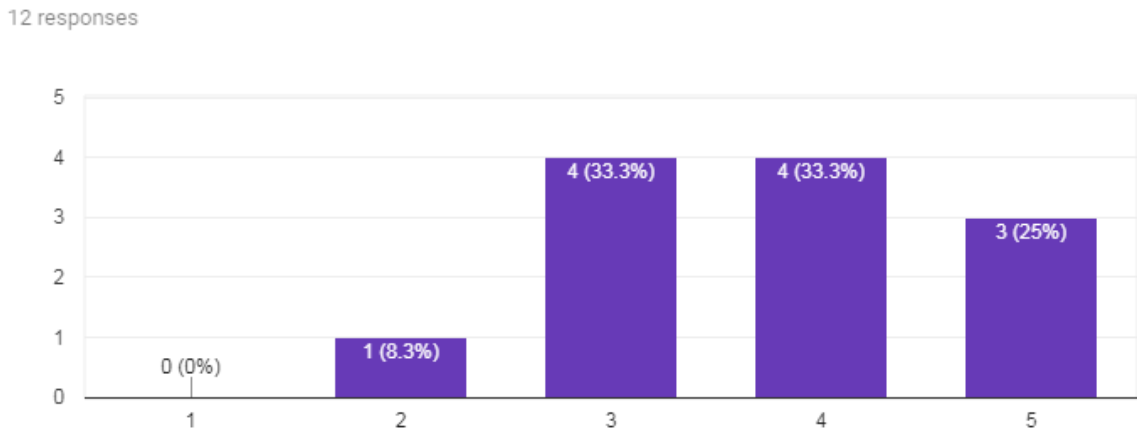
1: I don't know any instrument - 5: I consider myself a musician

Q.3.3 How would you rate the overall usability of the interface?



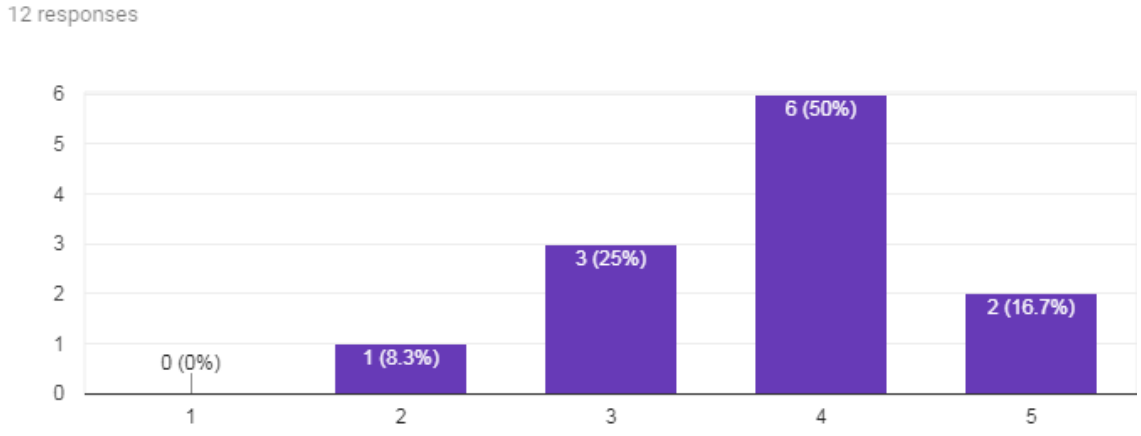
1: Not usable at all - 5: Very easy to use

Q.3.4 How would you rate the overall appearance of the interface?



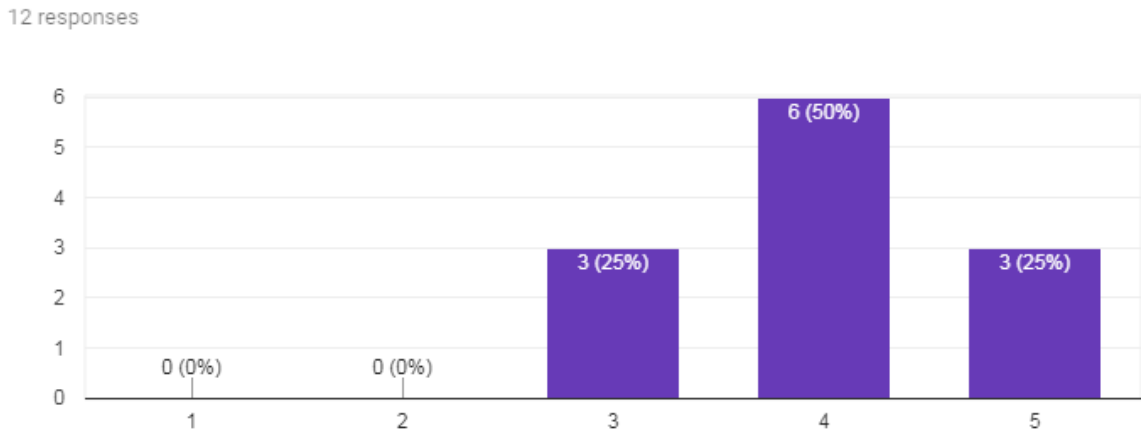
1: Very poor - 5: Very nice

Q.3.5 How would you rate the free interaction mode with the instrument?



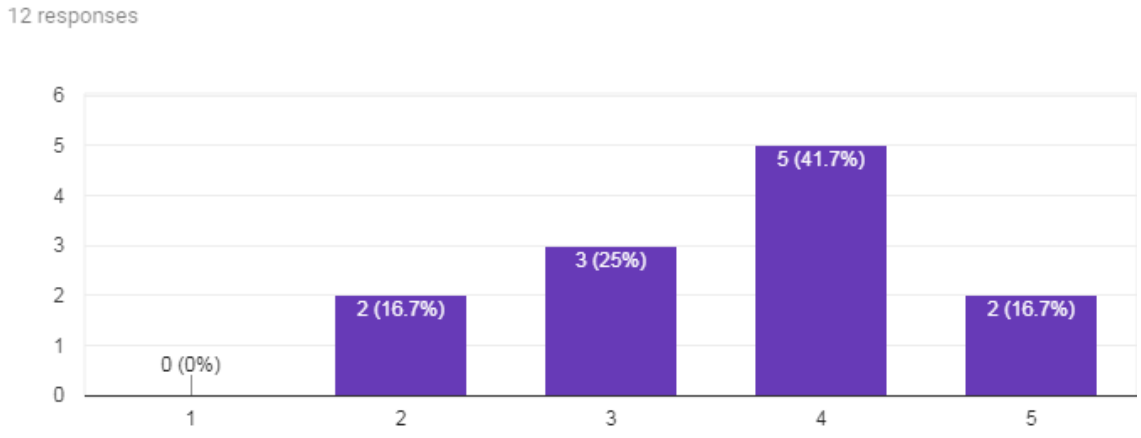
1: Very difficult - 5: Very easy

Q.3.6 How would you rate the sound quality of the instrument?



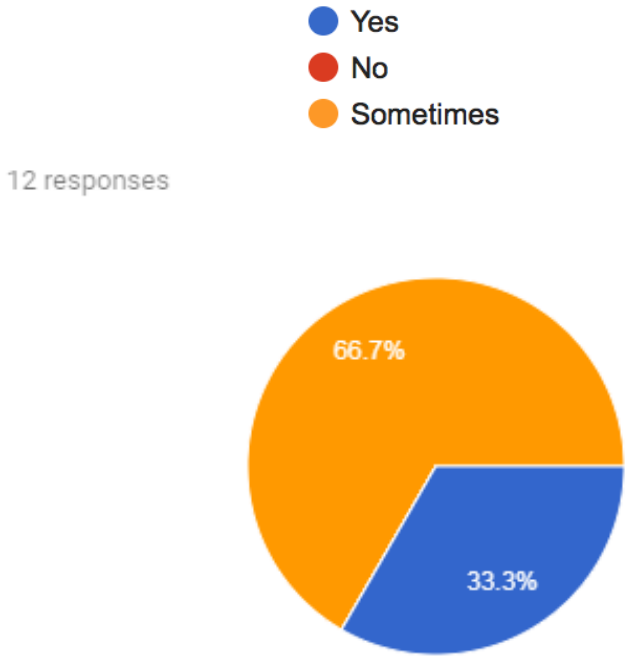
1: Very poor - 5: Excellent

Q.3.7 How would you rate the responsiveness of the instrument?

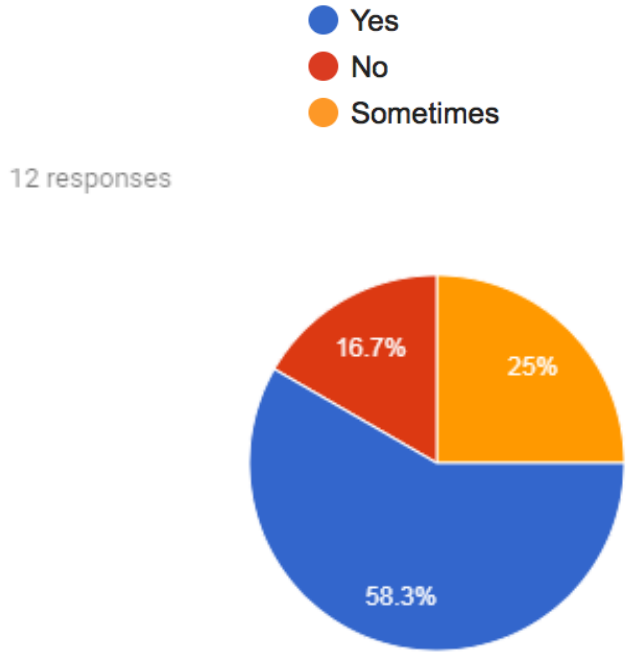


1: Not at all - 5: Very much

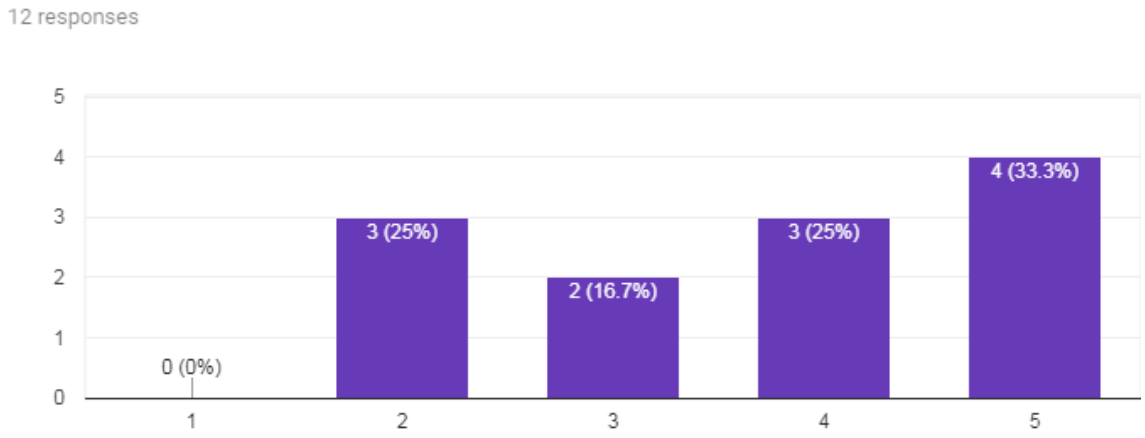
Q.3.8 Was it easy was to identify the notes produced from each string using the tuner?



Q.3.9 Was it easy to observe the different frequencies produced by the different strings in the 3D spectrogram?

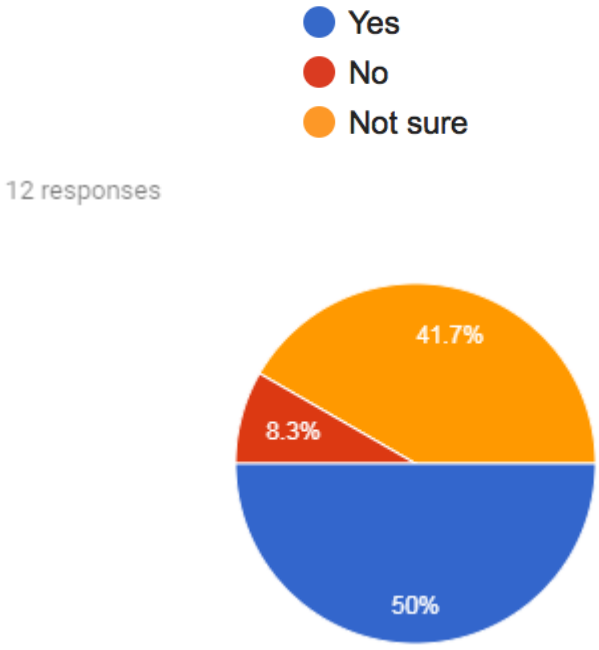


Q.3.10 How would you rate the gesture based interaction mode with the instrument?

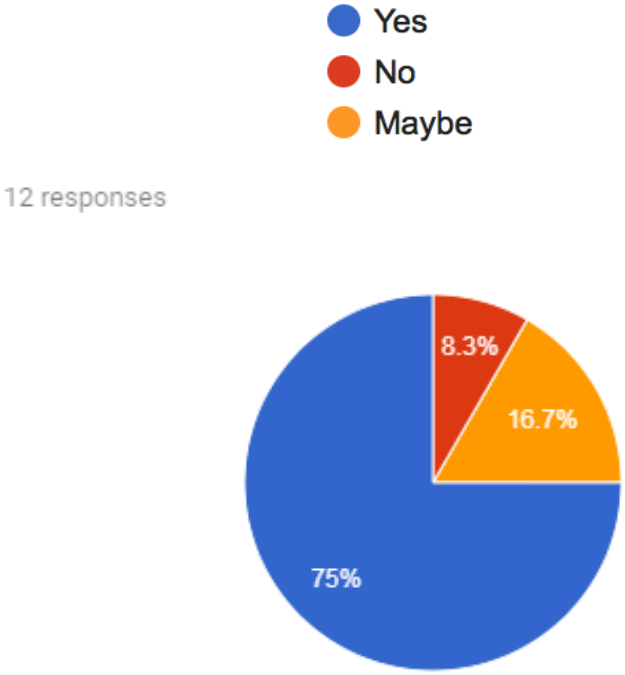


1: Not good at all - 5: Very good

Q.3.11 Was it easy to record the gestures of the performance?

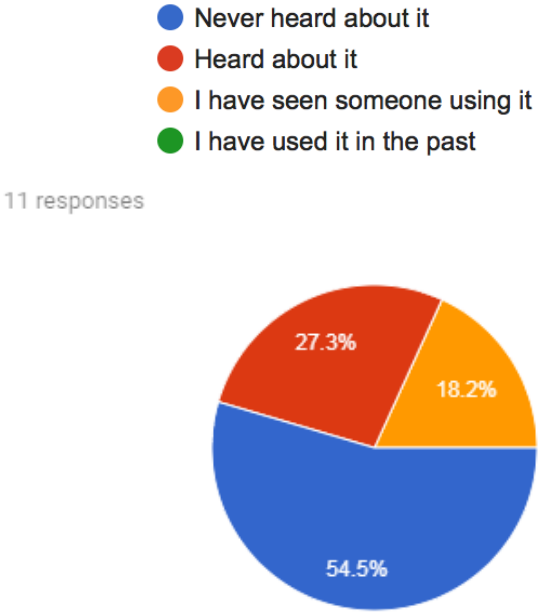


Q.3.12 Was it easy to record the audio of the performance?

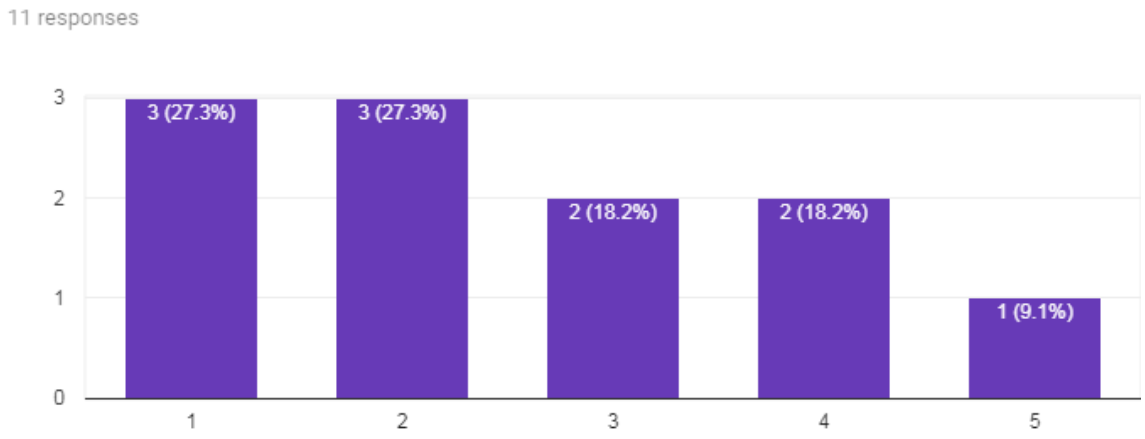


A.4 3D Musical Instrument Performance (with Kinect) Activity Environment

Q.4.1 Do you know the Kinect sensor?

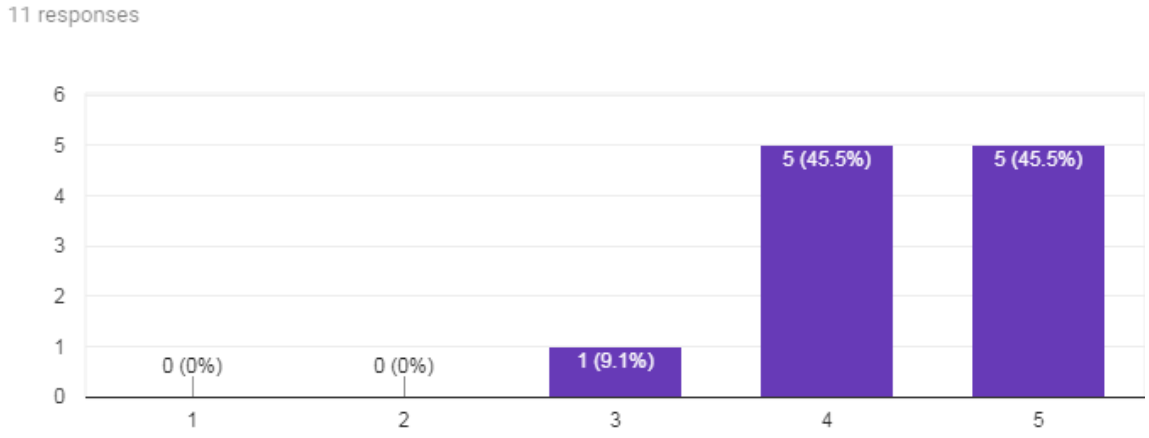


Q.4.2 How familiar are you with playing a musical instrument?



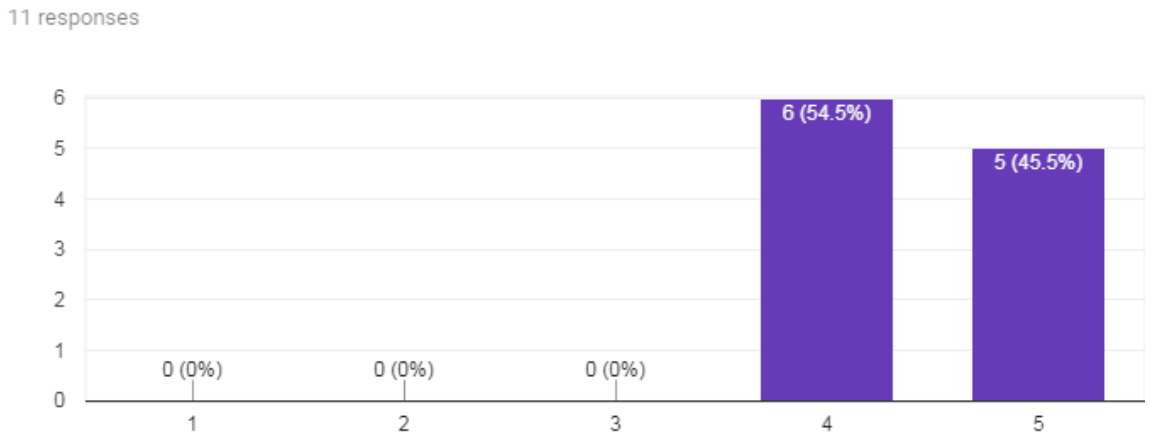
1: I don't play any instrument - 5: I consider myself a musician

Q.4.3 How would you rate the overall usability of Kinect performance tool?



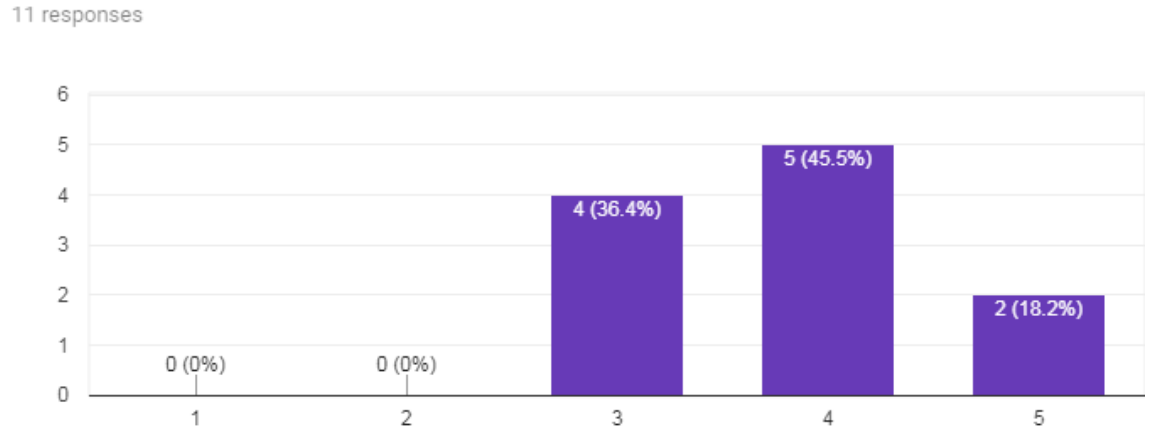
1: Not usable at all - 5 Very easy to use

Q.4.5 How would you rate the sound quality of the instrument?



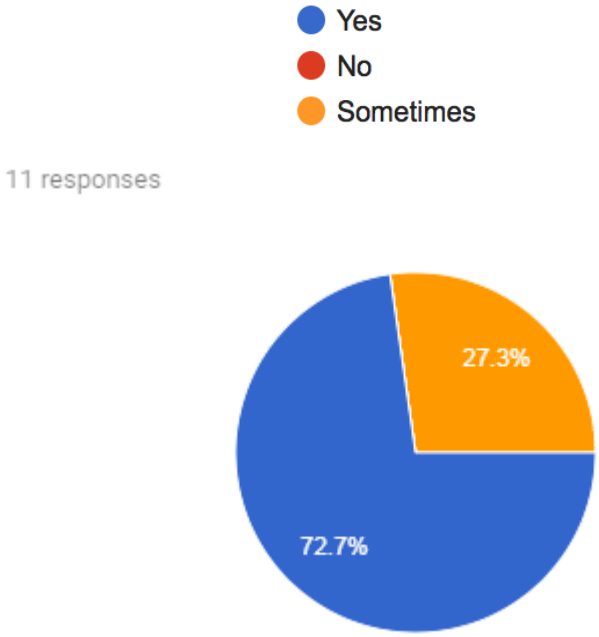
1: Very poor - 5: Excellent

Q.4.6 How would you rate the responsiveness of the instrument?

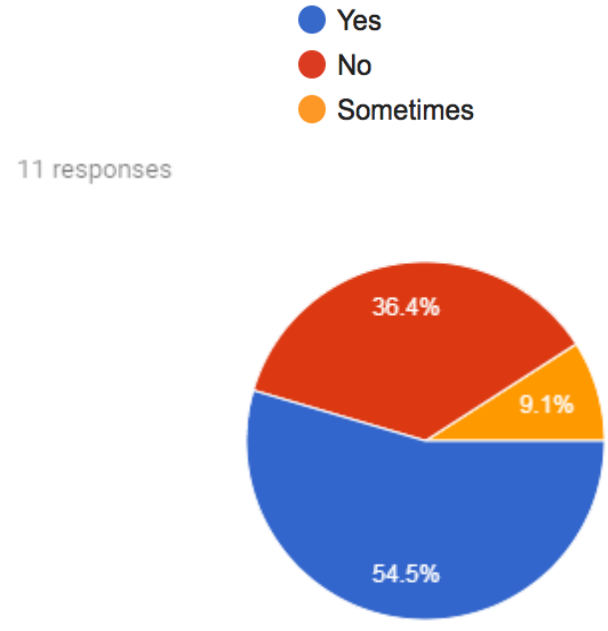


1: Not at all - 5: Very much

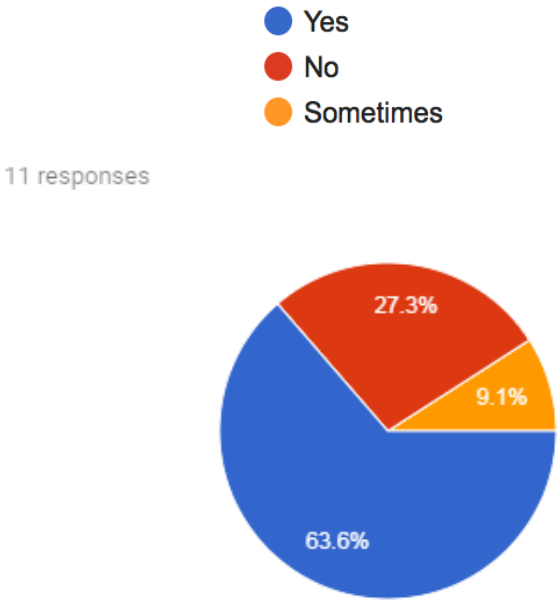
Q.4.7 Was it easy to identify the notes produced from the instrument using the tuner?



Q.4.8 Were you able to control which notes the instrument produces?

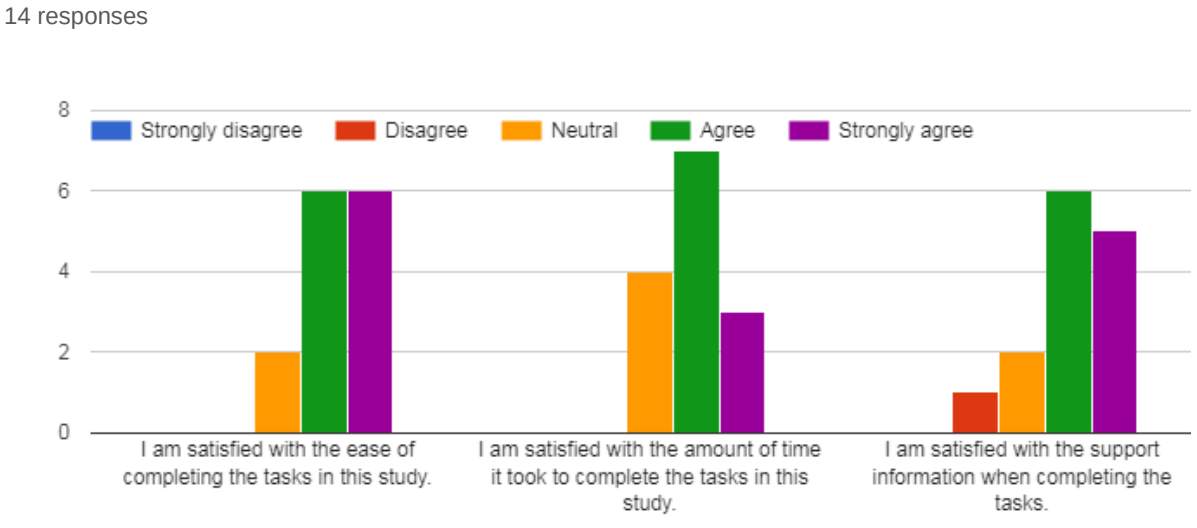


Q.4.9 Were you able to control the volume of the note that the instrument produces?

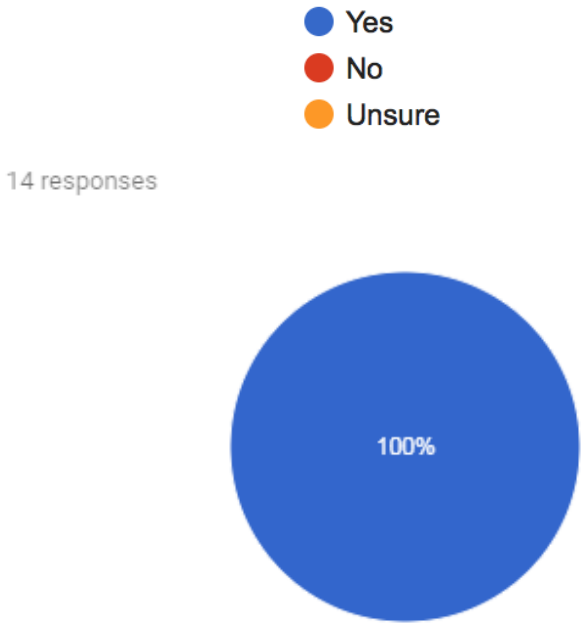


A.5 Drawing Canvas for Music Creation Activity Environment

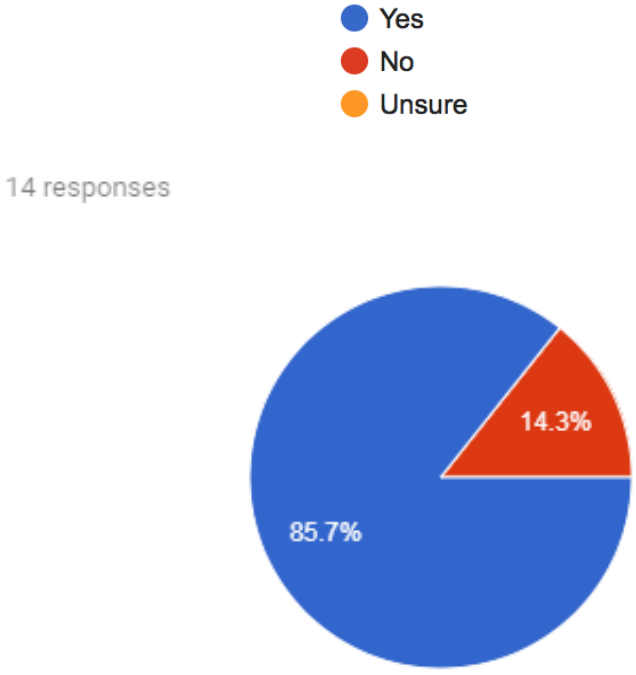
Q.5.1 How friendly is the activity environment?



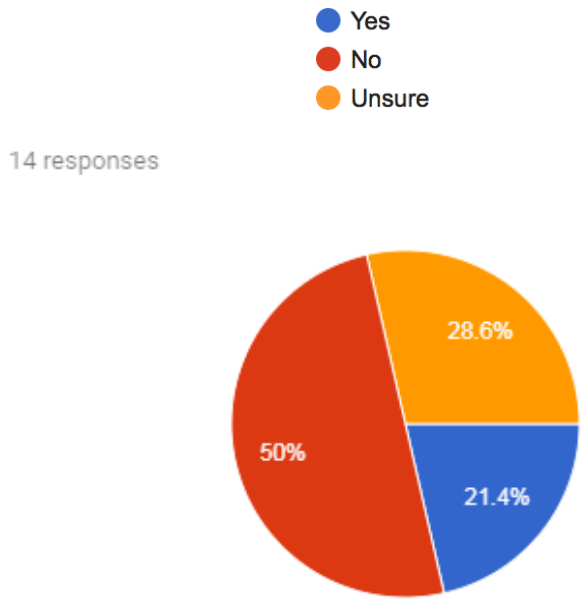
Q.5.2 Was it clear for you, that the environment is composed of three parts, the drawing canvas in the middle, the control buttons at the bottom and the visualization views on the right?



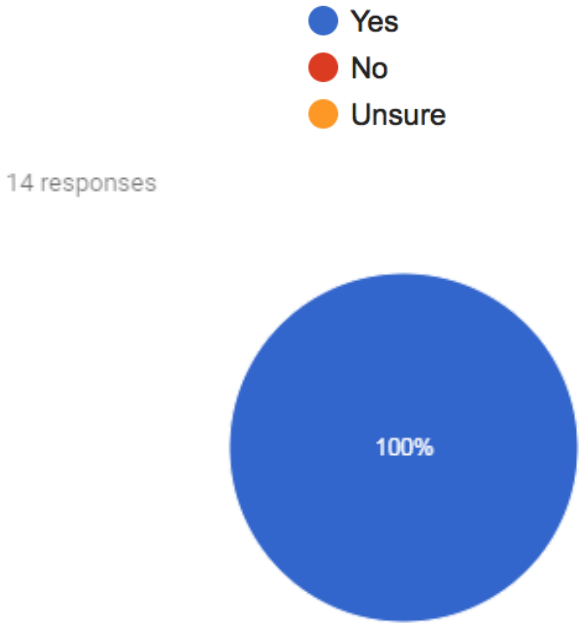
Q.5.3 Was it clear for you, that the different colors that are available for drawing, correspond to different timbres?



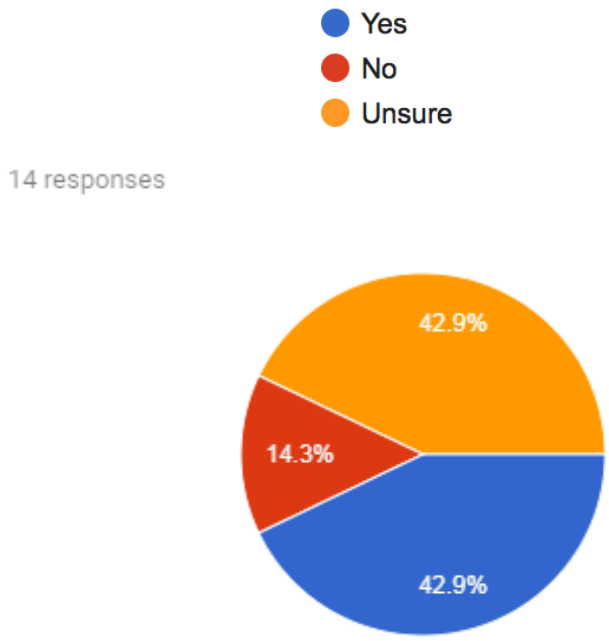
Q.5.4 Was it clear for you, that the pen erase button (or mouse right click otherwise) can be used to delete strokes?



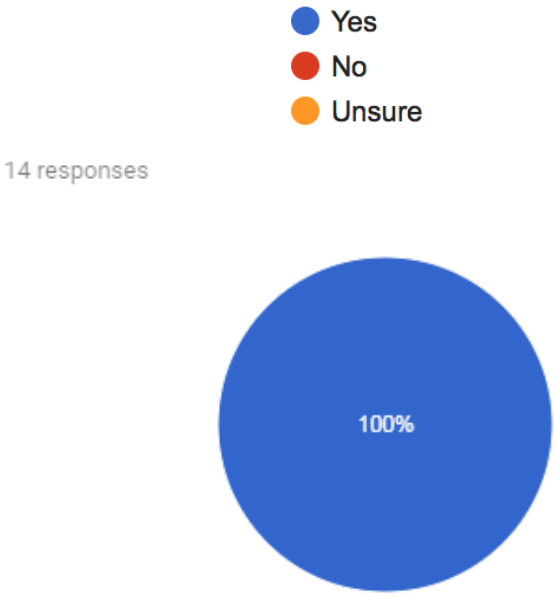
Q.5.5 Was it clear for you, that you can play the whole drawing by clicking on the “play” button?

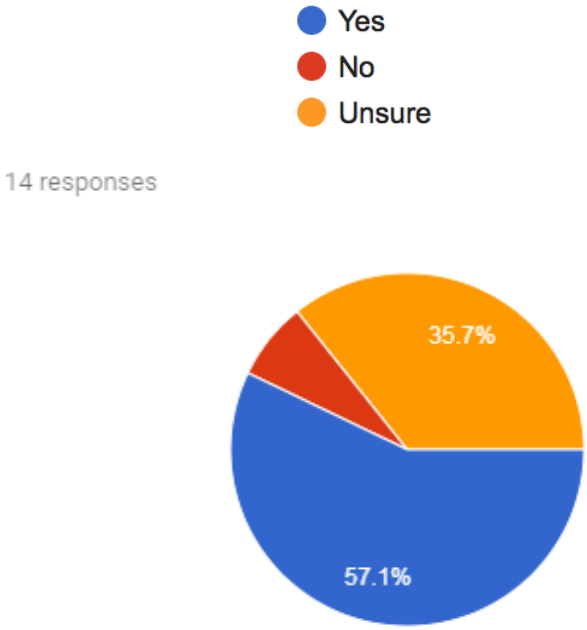


Q.5.6 Was it clear for you, that you can activate the stick to line option, to force drawing on the note/frequency lines?

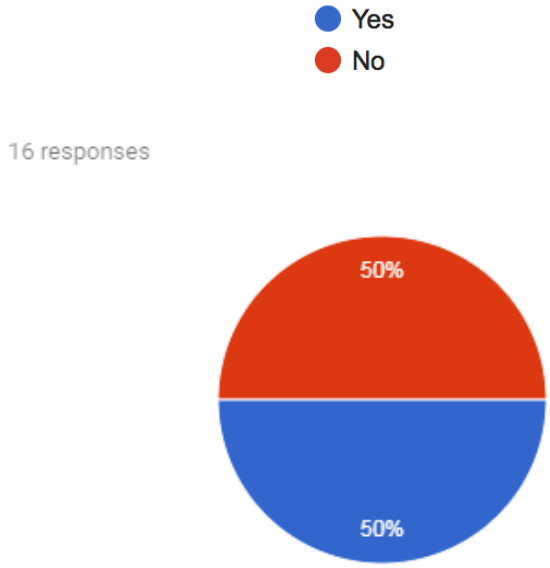


Q.5.7 Was it clear for you, that anytime sound is produced, it can be visualized in the visualization panel on the right?

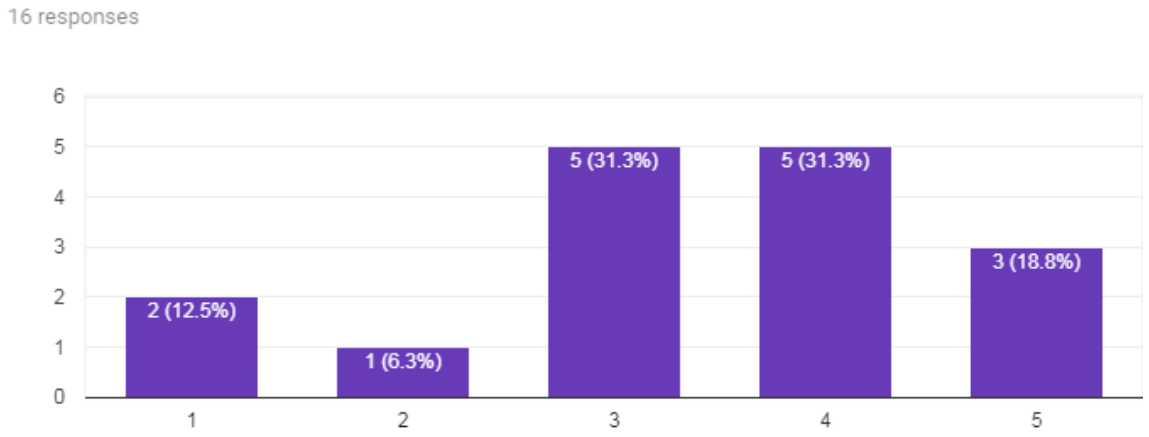


Q.5.8 Was it clear for you, that the visualization panel includes three views: 1) Waveform view 2) Fourier transform view 3) Spectrogram view


A.6 Geometry and Algebra Activity Environment

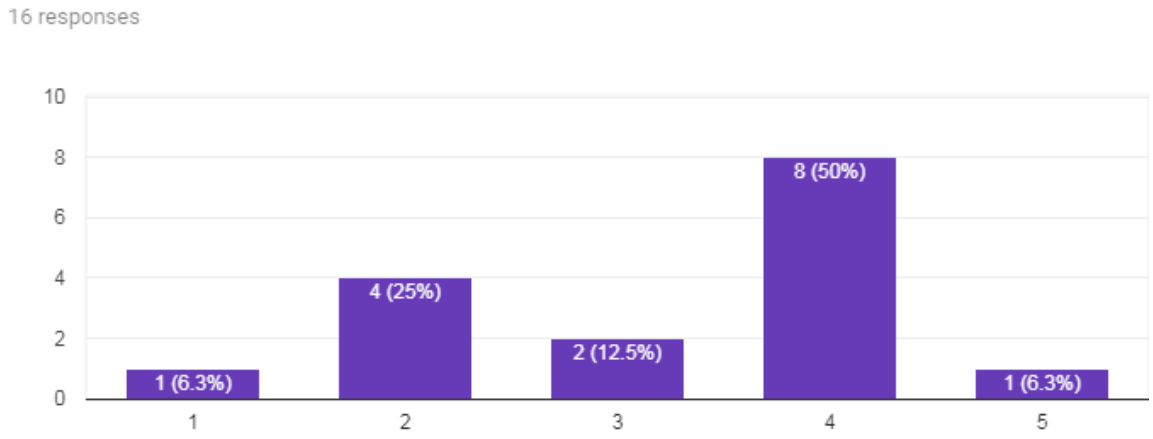
Q.6.1 Have you ever used any Dynamic Geometry or Dynamic Maths environment?


Q.6.2 How handy was the use of the various tools?



1: Very hard to use (some tools) - 5: Very easy and intuitive

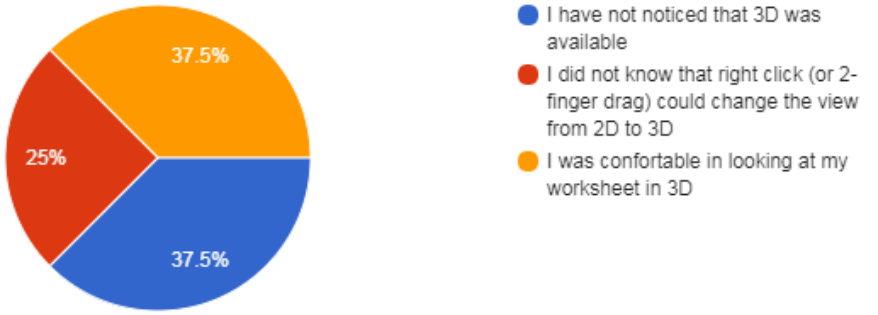
Q.6.3 Was it difficult to open the piles containing the tools?



1: I could not figure out what piles are and how they work - 5: It was very easy to use them

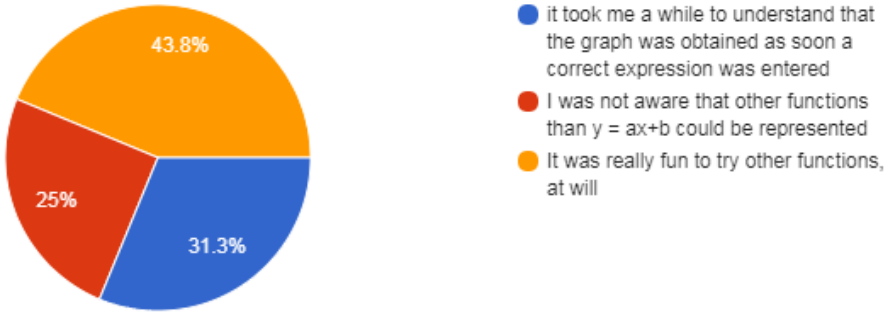
Q.6.4 Did you ever make use of the 3D view?

16 responses



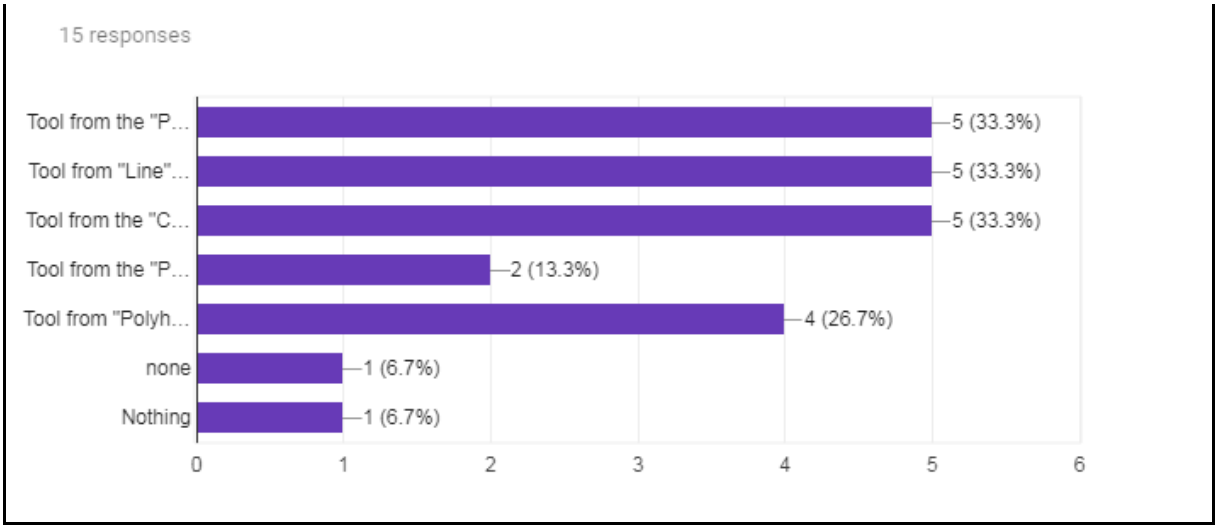
Q.6.5 Did you try to graph other functions?

16 responses



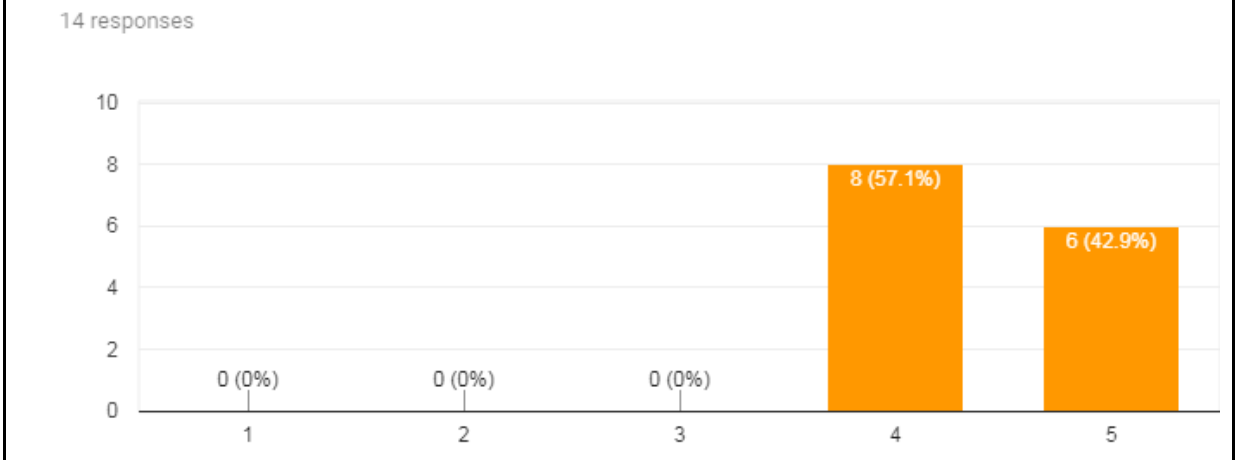
Q.6.6 What other tool have you tried?

- Tool from the "Point" pile
- Tool from "Line" pile
- Tool from the "Curve" pile
- Tool from the "Polygon" pile
- Tool from "Polyhedron" pile
- Other (added at the end of each list)



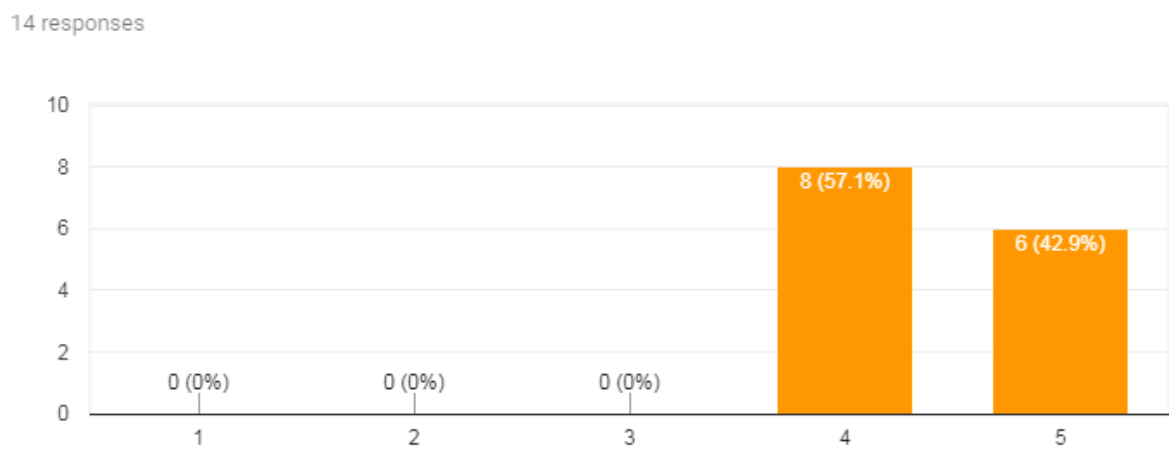
A.7 Sonification of Mathematical Equations Activity Environment

Q.7.1 Overall, rate how difficult or easy it was to complete the tasks.



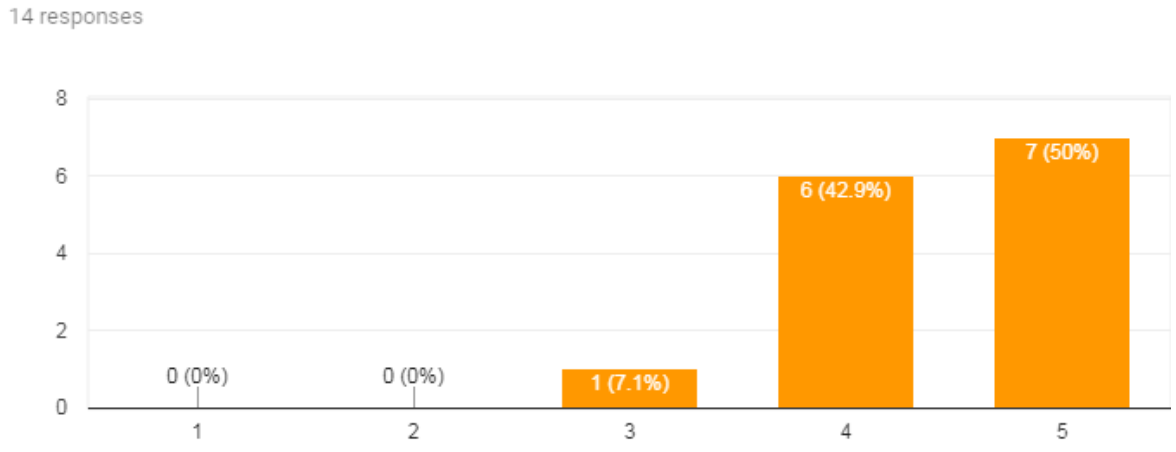
1: Very difficult - 5: Very easy

Q.7.2 Overall, rate how easy or difficult was it to figure out the correct icons and sequence of actions.



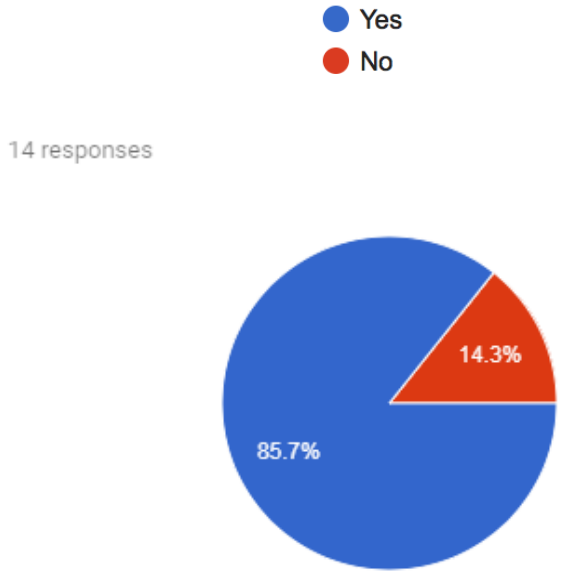
1: Very difficult - 5: Very easy

Q.7.3 Overall, I am satisfied with the amount of time it took me to complete the tasks in this study.

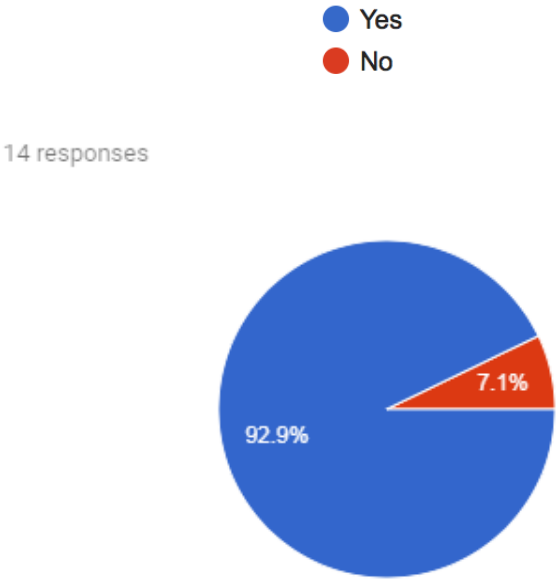


1: Very difficult - 5: Very easy

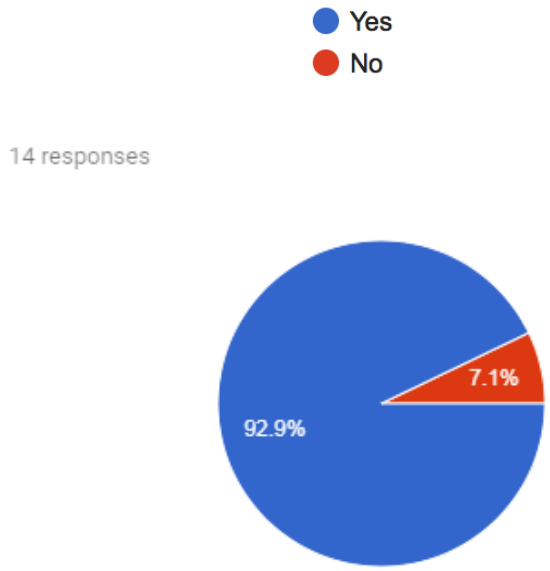
Q.7.4 Was it clear for you that the □ icon allows you to hand-draw geometric shapes?



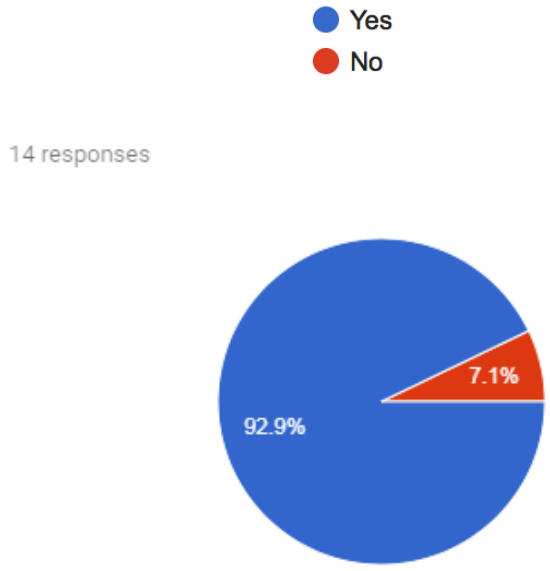
Q.7.5 Was it clear for you that the x^2 icon allows you to open the Math Editor?



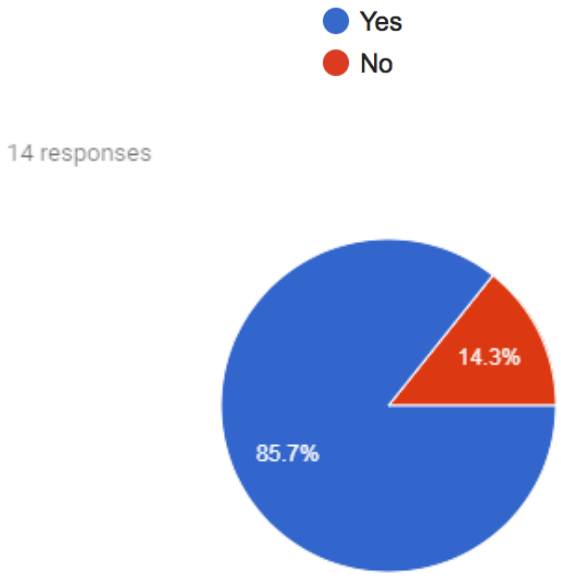
Q.7.6 Was the recognition engine able to correctly transform the strokes into geometric shapes?



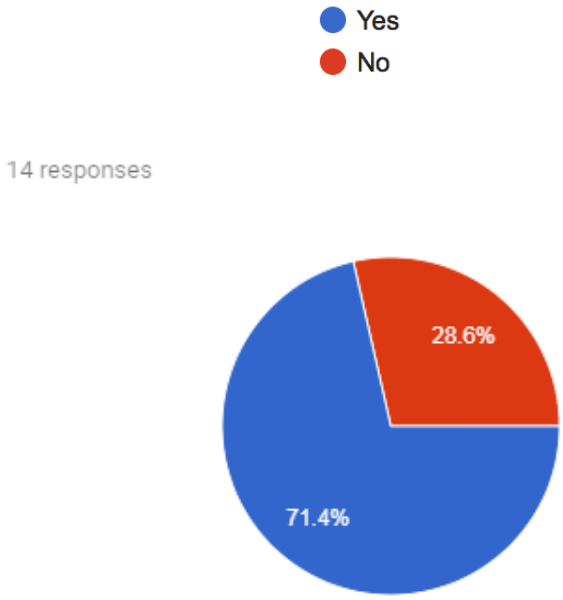
Q.7.7 Was the math recognition engine able to correctly recognize the strokes into the proper math equation?

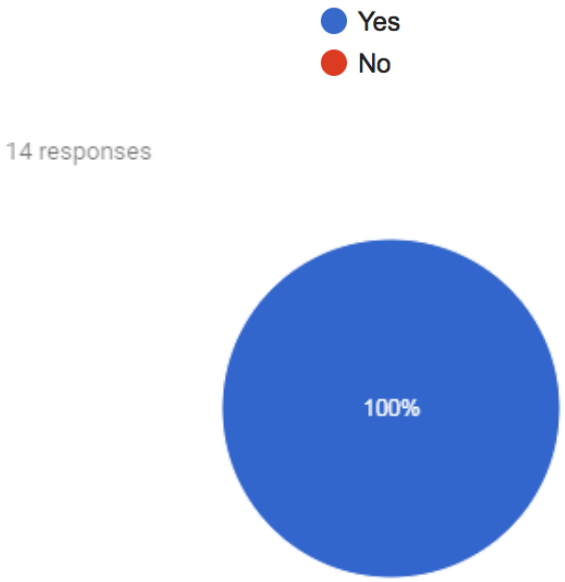


Q.7.8 Was it clear for you the relationship between the y-axis value and the frequency played?



Q.7.9 Was it clear for you that the trash icon (upper-right part) allows you to delete the drawing canvas?



Q.7.10 Was it clear for you that you can play every geometric shape by clicking on the “play” button?


B. iMuSciCA's pedagogic fit and value as seen by a Greek teacher of mathematics

The following contains excerpts from an interview conducted with an Upper Secondary Mathematics teacher from the Experimental Music School of Pallini in Greece, who had explored the 'Let's Listen to the Thales Theorem' pedagogic scenario.

"When following these particular scenarios in a "regular class" (non-Music School), an introduction to Music is required. Despite the fact that Music is the main course of the schools' curriculum where I teach, students understand what I tell them as completely new. Some students even look bewildered when I tell them about intervals and numbers. Music background is essential when following these scenarios.

An exercise related to "Mathematical Progressions/Sequences" for the 1st grade of Upper Secondary School would be interesting to follow using iMuSciCA. In "regular" schools (without music curriculum), they avoid it. It is related to frequencies and it introduces the solution of the twelfth root of 2 when exploring the 12-note musical scale. iMuSciCA can contribute to such kind of lessons. But it is very important for the project scenarios to determine their position towards the every-day teaching practice. While their purpose seems to be auxiliary, the detail of the scenarios seems to seek to replace a conventional lesson.

The expansion of the project scenarios into other forms of performance arts is also particularly important.

For example, in my school, a group of 6 to 7 students will form a small play by representing geometric shapes with the help of iMuSciCA tools. The group is divided into sub-groups for stage play, live drawing and live music. This drama exercise is based on a plot of points and lines that will correspond to music, according to the plot that is freely developing as a theatrical work. While the original design was based solely on geometry and drama, it seems that iMuSciCA can contribute to broadening the concept of collaboration among students not only through stage performance but also through "performing" in a broader sense in which Music plays a decisive role.

In particular, it would be interesting for instance to draw lines using the DrawMe tool while their intersections will be reflected with sound (or music) wherever this is possible. The point of intersection from the resulting shapes of a drawing, can be treated as an event which can be editable - that is to define measurable lengths, arcs, etc. The geometrical data generated can then be transferred to the CABRI environment for further process. This transfer can finally be repeated vice versa, allowing the measurements from the CABRI environment to be sonified in DrawMe."