ColourSphere - A Colour-coded Microtonal Instrument

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Musical instruments that enable the player to play microtones are either continuous or use discrete steps. The instruments that use discrete steps are restricted to one step size. This project aims to combine microtonal systems of different step sizes into one instrument, clearly displaying their relation and enabling to use them together. Our research question is, is it possible to create an intuitive, consumer-friendly, and easily approachable microtonal interface without losing any of the necessary functionality to make the instrument truly microtonal? We apply a colour-coding scheme to increase fluency of use and a modifiable scale. The results of our user analyses display a clear preference for the colourful interface of our product and a concern for the ergonomy of the sphere-like design. Our biggest setback was insufficient time management for a project so intensive in its workload. In conclusion, ColourSphere was deemed as a satisfactory approach to microtonal interfaces. Implications and limitations are discussed.

1 Introduction

Western music divides an octave into twelve equal intervals. Each tone's frequency is 2^(1/12) times larger than it's predecessor. This way of determining the exact relations between intervals is called equal temperament [1]. While many instruments apply a method of dividing the tones according to an equal temperament division, frequencies lying in between also have the potential to create harmonies.

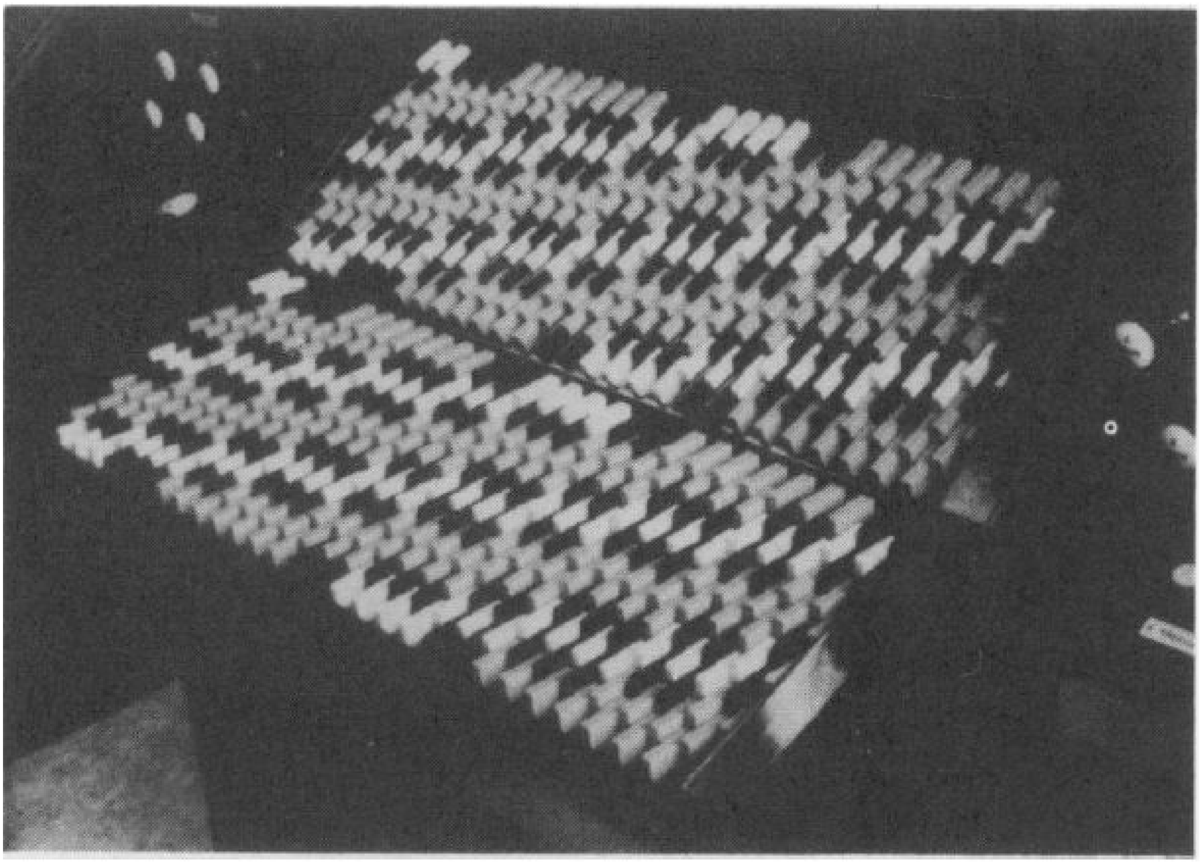
Frequency is a continuous scale so it can be divided into any number of equal or unequal parts. For example, nowadays instruments are often tuned in accordance to a standard pitch of 440 Hz, meaning that one pitch is tuned to 440 Hz, and other pitches are tuned certain semitones higher or lower from the standard pitch (Donahue, 2005). Our project focuses on dividing an octave into equal parts, as witnessed in Western music, however, we seek to explore the possibility of having more than twelve subdivisions, contrary to the most common Western instruments. Henceforth in this paper a subdivision of a specific number of tones will be referred to as a microtonal system.

While microtonal instruments are not by far a new addition to the arsenal of musical instruments [2], microtonal instruments have been difficult to approach for the user. This has been addressed previously, for example "The microtonal systems advocated here necessitate a rather thorough break with traditional thinking about music and its putative mathematical basis." [3], further supporting the claim that the usability of microtonal instruments is a challenge to the average user. The challenge here lies in adapting to a new way of thinking about the musical scales, compared to traditional instruments. The focus of this project is to create an interface or musical instrument that gives access to multiple microtonal systems at once, while retaining a reasonable learning curve for its usability. The goal is to present the microtonal systems and their abundance of tonal options without letting the user drown in the amount of keys on the instrument. The interface should make it possible to play large as well as tiny intervals using only one hand.

2 The Limitations of Contemporary Microtonal Interfaces

What previous microtonal instruments have provided for the user is an interface to play microtones with. The earliest examples of this include the Archicembalo and the just intonation harmonium of Colin Brown. More recently, microtonal instruments such as Rolky, a touch plate-based computerised microtonal interface, have implemented more functionality to programming your own tones for the interface, enabling the user to play multiple scales [2]. Ergonomy of the instruments has been seemingly satisfactory. However, whereas previous microtonal instruments have had increasing functionality, first-user usability has not been dramatically improved, evident by the somewhat intimidating user interfaces (see Figure 1). While the black, white, and grey keys of the Fokker organ provide some facilitating feedback, the approachability of the interface could be improved. Colouration as a facilitative approach has been applied in a smaller scale in Aaron Hunt's Tonal Plexus [4], however a full-scale colour-coding has not been evidently implemented as of now.

Figure 1. The organ of A. D.Fokker, in 31-tone equal temperament (1950). (Courtesy of the Verlag fdr systematische Musikwissenschaft.)



The problem we seek to address is that musicians who want to experiment with microtonality lack the means of doing so in conventional ways. Microtonal interfaces have been notorious for their lack of intuitive usability, even for above-layperson musicians. Continuous microtonal instruments like the violin or the theremin are hard to control. Discrete microtonal instruments like the tonal plexus of the Fokker organ tend to have so many keys or buttons they become hard to operate. Microtonal experimentation for musicians has been limited by a plethora of issues, mostly concerning the harshly off-putting learning curve [5]. Even intermediate musicians might face problems in using microtonal instruments, due to the inadequate usability for the uninitiated.

ColourSphere seeks to create an intuitive, consumer-friendly, and easily approachable microtonal interface without losing any of the necessary functionality. We address these issues by providing users with a colour-coded interface to signify which microtones are linked, enabling the user to create the sought harmonies. To solve the problem of being able to play large intervals as well as tiny intervals with one hand, the microtonal systems are mapped across a circular plane cut in half. Microtonal systems with a low amount of notes are placed closer to the centre than those with a large amount of notes. This is done proportionally to their number of notes per system. The effect of this is that all keys can have the same width. Also if large intervals are desired, the hand can move to a microtonal system with less notes where the notes lie closer together. If smaller more intricate intervals are desired, the hand can move outward to the microtonal systems with more notes.

Our primary user group is musicians with a keen interest towards microtonality or who are otherwise interested in experimenting with new instruments. As a secondary user group, our product aims to attract the curiosity of people with a general interest and experience with music, who might draw inspiration or enjoyment from experimenting with ColourSphere. In conclusion, our user group is experimentally driven musicians and other musically keen individuals.

3 Pretty Colours and Otherworldly Sounds - A Microtonal Playground

The ColourSphere will feature six keyboard belonging to six microtonal systems as seen in **Figure 2** in the appendix. The keys are attached to the front side of a wooden board. The back of the keys is coated with a capacitive stainless steel mesh to allow capacitive touch sensing. Holes are drilled in the wooden board to house the leds and to make room for the capacitive mesh to pass to the back side of the board. The keys will also cover these holes. On the backside of the board the parts are soldered together. Power to the leds will be provided by two rails (5 Volt and Ground) of thick copper wire next to the inner circle of leds. The thickness of the wire is necessary for the high amount of amperage all the leds pull, a thin wire would overheat. The two rails are connected to a large 5 Volt power supply supplying 30 Amps. To improve safety a circuit breaker is placed between the 5 Volt rails and the power supply, because short circuiting this amount of power could result in serious skin burns. In case of a short circuit, the circuit breaker will burn, disrupting the circuit, before any skin will get burnt. The leds have built in led driver chips with a data in and data out pin. This allows daisy chaining the leds and requires only one pin on the Arduino for the transmission of colour data. The capacitive touch sensing keys are attached to a simple "loop"circuit featuring only a 10 M Ohm resistor. The arduino sends a pulse through this system and measures the time this pulse takes to pass through this circuit. When the touch sensor is touched, the body of the user forms a large capacitor. This influences the time it takes for a pulse to pass through the circuit, thus enabling touch sensing.

To improve navigation inside the microtonal systems the keys will be backlit by RGB leds. As we have established, previous microtonal instruments have evidently not applied a method of a full-scale backlit colouration, although colouration in a smaller scale has been done before, as witnessed by Aaron Hunt's Tonal Plexus [4]. These leds allow a colour coding of the instrument. Giving keys a colour can help identifying the notes. The colour coding is not determined arbitrarily. It is designed in such a way keys with similar colours will sound more consonant than keys with dissimilar colours. This is done by colouring the keys in steps of fifths. For a system with n tones, the first tone-colour is picked to be red for example. The next key to be coloured will be a fifth up. To the Hue value of the colour, as existing in a HSV space, the value of 1/n will be added. Then the key will be coloured by this HSV value. The next to be coloured key will be a fifth up from this key etcetera. In order for this process to ever finish not every n can be picked. That's why a selection of microtonal systems was made that eventually return to their starting point in case of continuous modulation by fifths. The picked n-microtonal systems are: $n = \{12, 17, 19, 22, 29, 31\}$.

The keys themselves are half hollow transparent tubes. On the bottom of them a steel mesh is attached allowing capacitive sensing. This steel mesh allows the light of the RGB leds to pass through. These capacitive touch sensing keys are connected via a form of Charlieplexing [6] to an Arduino Mega [7]. To give the instrument more expressive capabilities an accelerometer and four pressure sensors are added. The accelerometer can detect shaking of the instrument indicating vibrato. The pressure sensors can detect how hard is pressed down on the keys to determine the loudness of the attack of the volume of the note for example. This pressure sensing will only work for all the keys at once, this design is chosen to reduce costs, since the only available pressure sensors were costly. This way phrases can be played with dynamic nuances, but it might not be the most ideal option.

The primary end users of our product are intermediate to experienced musicians. As such, our usability requirements for ColourSphere at the starting point of our project are as follows. Users' time to learn to play a previously unknown entry level measure with the instrument was set at one hour. Rate of errors by users was set at approximately one error in every four attempts, decreasing by half for every hour of practice. Subjective satisfaction refers to the user's satisfaction after using ColourSphere and it is measured on a Likert-scale from 1 to 5. The average predicted result was set at 4, above average. Usability is measured on the adapted System Usability Scale Questionnaire and we predict the results to average of 3.5, reversing the reverse-coded items. Mobility, or the ability to move our product from one place to another, is limited due to its size and weight. To move ColourSphere from a location to another, a motorised vehicle (e.g. a car) is needed. Playability is a multifaceted factor, defined as the time to learn to play a complete measure, the relative decrease in rate of errors, subjective satisfaction, and system usability.

4 Results and Evaluation

The results of our research consists of our first user evaluation, feedback given by peers and supervisors during and outside our presentation. Thus far we are still developing the prototype for a second user analysis to gain further feedback on how to better our product. The feedback we have received as of now has been mainly positive, however, certain considerations have been brought to our attention.

4.1 First usability test and presentation

Participants. Participants were recruited from co-author Lamers' music band colleagues, as they were deemed to possess above elementary knowledge of musical instruments and their usage. The number of participants was 4, 3 male, 1 female, and they were aged between 20 and 26.
Materials and design. A paper mock prototype of the colour-coded microtonal interface was presented to the participants. They were then asked to imagine what it would be like to play this instrument and "play", that is, tap the paper with their fingers, on the mockup. They had to evaluate what was good and what was bad in the design that was provided.
Results. The colour-coding was deemed to be attention-grabbing and increasing ease of use, due to the feedback given by the participants. Participants indicated that the bright colours made the interface "interesting to approach and play with" and that they "can imagine it being fluent to play with the matching colours". The angle of the spread in the interface was criticised as being uncomfortable. Participants mentioned "it might start to hurt the wrists to play in this angle for a longer time".

The results of our first user test indicated that the colour coding system was deemed as the most enjoyable facet of our interface. Elaborating further, the participants enjoyed the fact that they can make a link between the colours they see and the sounds they hear. On the critique towards our design, participants mentioned that the inner circles of the instrument seem to be less comfortable to play, because the hands need to be held in an uncomfortable position.

After our first presentation to our peers, the extensiveness of the development process was brought to our attention, both as a praise and as a criticism. To clarify, our product's capabilities to answer the need for an easy-to-use microtonal instrument was recognized but also the amount of effort and time consumed in building our product was highlighted and it was brought to question how quickly a working, transportable prototype for the next user analysis and the final presentation can be brought. It was also mentioned as a sidenote that people with synesthesia might not agree with the pairings of colour and sound that we have chosen.

4.2 Second usability test

In the second user test we seek to find out how easy it is to understand the interface with and without the colour-coding. In particular, we seek to answer if ColourSphere yields above average results in playability. We also for the first time get the chance to actually play the instrument, so playability can be determined. Our first hypothesis is that colour-coding results in fewer trials in succeeding in playing the determined melody. Our second hypothesis is that colour-coding results in a more usable and pleasant experience for the user.
Method. The second user test will consist of time and error measurement, a subjective satisfaction measure, and an adapted System Usability Scale (SUS) questionnaire. The test will involve four groups, divided into experimental and control conditions. Both groups must play the melody "Twinkle twinkle little star" succesfully. One group will play on the instrument with the mentioned colour coding, meaning that all the colours of the board are lit, indicating the relation between the keys. The other group has to play on this instrument with the colour-coding disabled, instead the keys are alternating in red and yellow. Both of these groups are split into groups that use "key restrictions". One group uses key restrictions set to the major scale. In this case only the keys associated with the major scale are lit and can be played. The keys outside the major scale do not respond. The control group has no key restrictions, so all keys are responsive and the keyboard uses the chromatic scale. The amount of tries a subject needs to succeed playing Twinkle twinkle little star is

measured. A “try” is defined as the first note being played after a start signal until the last note being played. The last note is the first wrong note being played or the last correct note of the melody. The first note can not be a wrong note, since it is not determined in what key the melody has to be played. Both groups have no knowledge of the colour-coding or key restrictions being turned on or off in the other group. To reduce the necessary time to do one experiment, the amount of tries caps out after 50, beyond this no tries are measures. After the measurement, participants can play with the interface freely. Finally, the participants are asked to fill out a questionnaire.
In the future it might be possible to let the participants play a measure of an actual microtonal pice like Towards the Continuum, a microtonal composition by Dolores Catherino (see Appendix) successfully.

On top of the Subjective Satisfaction measure and the System Usability Scale Questionnaire (see Appendix), the questionnaire will have the following questions:
On a scale of 1 to 10 with 1 being “not at all” and 10 being “extremely”:

“How intuitive did you find the interface?”
“Was it easy to navigate the instrument?”
“How eager are you own this instrument?”

Further questions include:
“What did you like about this instrument?”
“What did you dislike about this instrument?”
“Do you have any suggestions of improvement?”

The results are shown in the appendix.

Evaluation
The results of our first user analysis indicated the layout of the keys would benefit from some tweaking. The keys could be lain out more straight. Also the keys could gradually become less wide as the number of keys increases. These ideas will be worked out in a next prototype phase.
Although there were too few subjects (four only one per group) in user test to draw any conclusions. It seems that the key restrictions improve the playability a lot more than the color coding does. The subject that had no key restrictions suggested key restrictions. One subject suggested adding pressable keys. It might be an idea to make a key pressable as well as touch sensing. The idea of adding extra note information can be worked out by adding labels on or around the keys or even adding displays in the keys, although the latter might be costly. Making the design more like a piano is not an option since this is not in line with the idea of even spacing of notes. The mentioned fragility of the prototype will be fixed in later prototypes, since more computer aided design will be used such as 3d printing, circuit board etching and computer controlled milling. These techniques will create a more slick and professional looking prototype.

Limitations
The current design lacks ergonomy. To solve this, computer aided design will be necessary, for example 3d printing or using a computer controlled milling machine. This is for future work to uncover.

The tracking on the current device is not accurate enough. Often two notes are played together when the intention was to play only one note. When trying to play more than one note at once the keys are not picked up anymore. An earlier prototype involved keys made of capacitive material, instead of capacitive material being mounted below a surface. Due to this more direct contact the earlier prototype used 1 M ohm resistors. The current prototype uses 10 M ohm resistors since this allows capacitive sensing through a layer of non capacitive material. The use of capacitive foil on top of the keys combined with 1 M ohm resistors will probably resolve these tracking issues. Due to the high cost of capacitive foil this was not used in the current prototype.

For the best and most accurate tracking it is a good idea to learn more about the specific materials used in known capacitive touch devices like the iPad.

5 Conclusion and Discussion

In conclusion, ColourSphere is a novel approach to microtonality, in that it applies a method of RGB backlit keys to highlight the differences of the keys to the user, a spherical formation of the keyboard, and a programmable interface to different scales. Comparing to earlier microtonal instruments, our product is the first of its kind to apply LED backlit colour-coding and a spherical form. We sought to investigate if it is possible to create an intuitive, consumer-friendly, and easily approachable microtonal interface without losing any of the necessary functionality to make the instrument truly microtonal. Our hypotheses were measured with two usability tests, first one of which was performed with a mock-up, and the second one which was performed on the final prototype. Participants were recruited from experienced musicians. The ratings of the participants were measured with freeform feedback, questionnaires, and rate of error and time measurement.

Results show that a colour-coded microtonal interface was found to be an attractive interface to approach for users. The main drawback of our designed interface was its ergonomy, also compared to previous microtonal models. Limitations of our results consist of lack of feedback on the advanced prototype, due to the time-consuming development process of a functional prototype. The microtonal interface made during the course of this project shows a rough idea of the final product. It gave light to a lot of complications that arise when going from an idea to an actual product. Although there was no time to add microtonal systems to this prototype, it taps into the need for microtonal experimentation with flexible modification and ease of use. If it were to become a serious musical instrument a lot more development has to be done. The instrument would benefit from more professional construction, different material use and overall more tweaking. Future prototypes will be better suited to learn about the distinct sounds of each microtonal system.

It is noteworthy to assume relative challenges for new users of ColourSphere. Even though in our design we aimed for the best possible usability, microtonal instruments require a different cognitive model compared to traditional instruments. This poses a challenge that is difficult to address with the current design. However, the fact that different keys are colour-coded differently and matching ones similarly, helps new users get a foothold in thinking in terms of microtones. Ultimately, a learning method for microtonality is a curious play with thought, paving way for future work.

6 Future Work

All the feedback gathered with this project can be used to further develop the idea of the microtonal interface. Drawing from the received feedback, future work should focus on improving the tracking and ergonomy first and foremost. A crowdfunding campaign can be started for example. This would allow the use of more expensive techniques like 3d printing, milling the interface of even using other materials that better facilitate the expressiveness wanted in a musical instrument. Furthermore, an integrated learning software to help users get started with microtonal instruments could be implemented as a part of the design.

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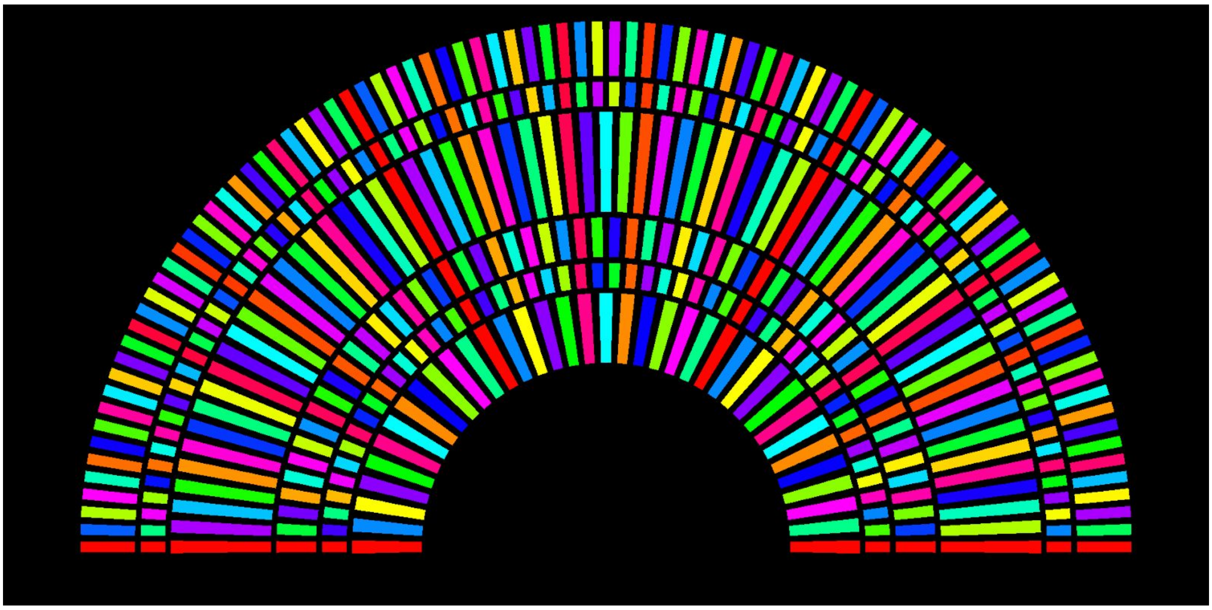
Appendices

Figure 2. *Microtonal interface layout.*



The layout of the keys with the described colour coding. Displayed are three octaves. From inside to outside the n-microtonal systems are visible for n = {12, 17, 19, 22, 29, 31}. Note that all the systems share the "red" note. This picture was generated using an algorithm describing the placing of keys for microtonal system combinations, written in c++ using openGL.

Subjective Satisfaction Measure

On a scale from 1 to 5, how satisfying was the experience of playing with ColourSphere?

Not at all satisfying 1 2 3 4 5 *Extremely satisfying*

System Usability Scale Questionnaire

See the next page for the Questionnaire.

System Usability Scale

	Strongly disagree 1	2	3	4	Strongly agree 5
1. I think that I would like to use this system frequently					
2. I found the system unnecessarily complex					
3. I thought the system was easy to use					
4. I think that I would need the support of a technical person to be able to use this system					
5. I found the various functions in this system were well integrated					
6. I thought there was too much inconsistency in this system					
7. I would imagine that most people would learn to use this system very quickly					
8. I found the system very cumbersome to use					
9. I felt very confident using the system					
10. I needed to learn a lot of things before I could get going with this system					

User test 2 results:

Color Coded - No key restrictions, chromatic
Subject 1

Tries needed: 21

SUS
1. 3
2. 3
3. 2
4. 1
5. 2
6. 2
7. 2
8.3
9. 3
10. 4

“How intuitive did you find the interface?”
9
“Was it easy to navigate the instrument?”
4
“How eager are you own this instrument?”
6

Further questions include:
“What did you like about this instrument?”
Beautiful colours, the flashing when touch.
“What did you dislike about this instrument?”
Not like a piano or accordion, that’s confusing. Piano experience is intervening.
“Do you have any suggestions of improvement?”
Match piano keys.

Color Code - keys restricted to major
Subject 3

Tries needed:12

SUS
1. 3
2. 1
3. 4
4. 1
5. 3
6. 3
7. 4
8. 2
9. 4
10. 3

“How intuitive did you find the interface?”
8.5
“Was it easy to navigate the instrument?”
7
“How eager are you own this instrument?”
2

Further questions include:
“What did you like about this instrument?”
The colours and the sound.
“What did you dislike about this instrument?”
Tracking issues, did not like the key restriction.
“Do you have any suggestions of improvement?”
Better tracking, remove the keys that don’t work (subject does not know that they can be put on). Make more portable. Make more professional, now it looks fragile and flammable.

Non Color Coded - No key restrictions, chromatic
Subject 2
Tries: 50+ (capped out)

SUS
1. 1
2. 4
3. 1
4. 5
5. 3
6. 3
7. 2
8. 5
9. 1
10. 5

“How intuitive did you find the interface?”
7
“Was it easy to navigate the instrument?”
2
“How eager are you own this instrument?”
1

Further questions include:
“What did you like about this instrument?”
The colors
“What did you dislike about this instrument?”
Can’t press in the keys, only touch. Very unclear which tone is which.
“Do you have any suggestions of improvement?”
Pressable keys. Seperate color for note (colorcoding). Drawn around the keyboard extra note name information.

Non Color Coded - Keys restricted to major
Subject 4
Tries: 4

1. 4
2. 1
3. 5
4. 1
5. 4
6. 2
7. 5
8. 2
9. 5
10. 1

"How intuitive did you find the interface?"
9
"Was it easy to navigate the instrument?"
6
"How eager are you own this instrument?"
8

Further questions include:
"What did you like about this instrument?"
Key restrictions, works like a piano.
"What did you dislike about this instrument?"
Nothing
"Do you have any suggestions of improvement?"
Make chromatic

Toward the Continuum by Dolores Catherino, sheet 1 of 3 (2012)